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ENGINEERING:

An Illustrated Weekly Journal.

EDITED BY WILLIAM H. MAW AND B. ALFRED RAWORTH.

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THE NEW QUEBEC BRIDGE.

THE successful testing last month of the new Quebec Bridge marks the completion of a great work which has claimed the attention of engineers for many years past, not only on account of its magnitude but also because of the serious vicissitudes which have accompanied its progress. The structure crosses the St. Lawrence River at a point about 6 miles above Quebec, and the erection of the first bridge* on this site was commenced in July, 1905. On August 29, 1907, this structure, while in course of erection, failed with most disastrous consequences, as we recorded fully at the time.†

The new Quebec Bridge occupies the same site as its predecessor, but with a slight modification in the location of its piers. The catastrophe to the first bridge undoubtedly influenced American bridge design for the good, as it emphasised in a way which a disaster of smaller magnitude would have failed to do, the necessity of far-reaching reforms in the design of compression members. A contributory cause to the accident was the ridiculously small sum set aside for professional advice, which made the provision of an adequate scientific staff impossible. When the erection of a second bridge, to replace that which had failed, was decided upon this lesson was duly taken to heart. In fact, the preparation of the plans for the official design of this new bridge is said to have cost 100,000*l.*, whilst to supervise the plans and erection of the structure as actually being built, a board of engineers was constituted composed of Messrs. C. N. Monsarrat, Ralph Modjeski, and H. P. Borden, who have been entrusted with the conduct of the whole of the work.

We have from time to time during the erection of this second bridge given accounts of its progress,‡ but now that it is completed we believe that our readers will be interested in having a consecutive account of its erection even if this involves the repetition of a certain amount of information which has already appeared in our pages. We therefore devote considerable space in our present issue to such an account. In connection with this we give in Figs. 1 and 2 on Plate XXI, a view of the completed bridge, and a view taken on the bridge showing the test load.

The new bridge differs materially not only from its predecessor, but from the "official" design on which tenders were invited in 1910. The most favourable bid on these official plans was that made by the Cleveland Bridge Company in conjunction with the Metropolitan Amalgamated Railway Carriage and Wagon Company. After much consideration, however, it was decided to accept an offer made by the St. Lawrence Bridge Company, of Montreal (formed by an amalgamation of the Dominion Bridge Company with the Canadian Bridge Company) for a structure which differed from the official design in a number of important particulars. Thus the carriageways were omitted, substantially lightening the load to be carried, and the idea of making any use whatever of the old piers was abandoned. In this way it was possible to keep the centre line of the new structure on the original location. One of the new main piers, is inshore, of the old and the other is at an equal distance nearer mid-channel so that the span remains unaltered. The anchor spans were similarly displaced, as shown in the diagrammatic view of the new structure which we reproduce in Fig. 3, Plate XXII. From this it will be seen that the main span is 1,800 ft. between centres of piers, and is composed of two cantilever arms of 580 ft. each and a central suspended girder of 640 ft. span under which there is a free headway at high water of 150 ft. The two anchor arm spans are of 515 ft. each, whilst the height of the main towers is 310 ft. between pin centres, and the width from centre to centre of trusses 88 ft. This width is constant from end to end as the greater ease of erection and manufacture was held to more than offset any possible gain that might be effected by splaying out the feet of the towers. The total length of the whole structure, including approach spans, is 3,239 ft. The bridge carries two railway tracks spaced 32 ft. centre to centre, and outside of these two foot paths, each 3 ft. wide, are provided for. The designed rolling load is 5,000 lb. per lineal foot on each track and two E60 engines so placed as to give the maximum stresses. The wind load was assumed at 30 lb. per square foot of exposed surface of the two trusses plus one and a half times the elevation of the floor, in addition to 300 lb. per foot run as a moving load on the exposed surface of the train. A wind load of 30 lb. per foot acting parallel to the bridge was also provided for, the exposed area being taken as one-half that assumed for the normal wind pressure. Views of the bridge in various stages of erection are reproduced in Figs. 4, 5 and 6, Plate XXII.

As will be seen, the new structure presents the appearance of a straight forward mechanical looking design, which is pleasing to the educated eye from its evident aptness. The lower chords of the cantilevers are straight throughout, which not merely facilitates the work of manufacture and erection, but in conjunction with the system of web bracing adopted, has been proved to reduce to a minimum the distortion of the structure under stress. To reduce the deadweight of the structure nickel steel has been adopted almost exclusively for the trusses of the suspended span and also in the construction of the river cantilever arms. The floor is, however, of carbon steel throughout, and the same material has also been used for the anchor arm spans, since the additional weight thus required acts as so much counter balance.

Special note should be taken of the character of the cantilever web members. The bracing, it will be seen, is of the K type, which minimises the secondary stresses, and was found on careful comparative studies to be lighter than the other systems investigated. Its great advantage in the present case lay, however, mainly in the great reduction it permitted in the overhang of the travellers used in the erection. By the use of this bracing the maximum overhang needed was reduced to 42 ft., or half a panel length, whilst two or three times as much would have been required if other forms of bracing had been adopted. At the same time the type enables the diagonal members to be subdivided into more manageable lengths, a matter of very considerable importance in view of the size of the structure. Finally, as was shown by Mr. Modjeski in a paper read* before the Franklin Institute during 1913, the deformation of the new structure under its load will be remarkably uniform in character.

A bridge has not merely to be designed on paper, but has to be erected, and the fact that work in the field is impossible at Quebec during a very large fraction of the year made it as necessary to study constructional questions as minutely as those of strength. Pin-jointed connections were adopted in view of the rapidity of erection they render possible, but eye-bars are not used as tension members save in the case of the top chords of the cantilevers. The tension members of the web, although pin-connected, are built up of plates and shapes, and are designed so as to be stiff enough to support their own weight during erection. Moreover, even in the case of the top chords, the eye-bars are enclosed in a light lattice framework stiff enough to carry them without sag. This plan considerably facilitated the work of erection as the panel lengths were such as to require two eye-bars to span them.

In view of the immediate cause of the disaster to the previous bridge, very special attention was paid to the design of the lower chord compression members. Numerous tests were made on models of these, but the "models" exceeded in size the principals of most bridges. The models of the lower chord members had four webs carefully interbraced. They measured 30 in. by 18¾ in. over all and were 18 ft. 6 in. long. The value of $\frac{l}{r}$ was 38 where l denotes the length and r the least radius of gyration of the member. The load was applied through pins. Three out of the four models tested failed by the buckling of the webs, and in the fourth the model bent in the plane of the webs. In no case did the bracing give way. The above models were of carbon steel. In other tests the comparative strengths of nickel and carbon steel members were compared, and from these it appeared that the elastic limit of compression members built of nickel steel was nearly twice as high as that of a duplicate made of carbon steel, whilst the ultimate strength was 54 per cent. more. In this way the adequacy of the bracing and of the stiffening generally was thoroughly tested.

In essentials the chords, as constructed for the actual bridge, consist each of four vertical webs braced together by lattice-bars at top and bottom and by a diaphragm plate at mid-height. Additional diaphragms transverse to this are provided at intervals. At the main pier each bottom chord measures 7 ft. 2 in. by 10 ft. 4 in. over all and has a cross section of 1,902 sq. in.

The total weight of the heaviest panel length of chord is about 400 tons, and to facilitate erection the whole was divided into four unit parts, the length being divided into two at the mid joint of the panel, and each of these sections was in its turn split longitudinally. In making the joints, every care was taken to secure a fair butting of the opposing surfaces, but sufficient rivets were provided at the same time to transmit safely the whole of the thrust. The webs were built up of four plates, stitch riveted together. One inch was the maximum thickness of plate used, and the thickest web measured 3¾ in.

The depth of this chord tapers uniformly from the main pier to the anchorage end, where the depth is 4 ft. 6¾ in., but the spacing of the webs is the same throughout. The pins to which the diagonals are connected do not pass through the lower chord itself, but through gusset plates riveted to these webs. There are thus two sets of pins at each panel point, one taking the vertical and the other the diagonal member.

The bridge members were built in exceptionally well equipped shops, specially designed for the work in hand. The equipment comprised machines by which the longest members could have both ends faced off dead parallel to each other simultaneously. The longest planing machine could finish at one setting a surface measuring 30 ft. by 10 ft. All sheared edges of plates were planed before the plates were assembled. Most of the rivet holes were drilled out of the solid, though for plates less than 1⅛-in. punching followed by reaming was permitted by the specifications. An unusual provision in the specification was one prohibiting the use of water or other lubricant in the drilling operations.

As already mentioned very special attention was given to questions of erection. It was decided to erect the anchor spans on false work, the river arms being erected by overhang. A peculiarity of the design of this false work lay in the independent support provided for the truss and for the girders carrying the traveller. To test the practical working of the arrangement decided upon a model of the whole span was made and was erected complete in the offices of the builders by means of a model traveller. A view of this model is reproduced in Fig. 7, Plate XXIII.

The main traveller, which weighed nearly a 1,000 tons, was 210 ft. 3 in. high from rail level to the highest points of the gantry cranes fitted on its top platform. Its general character is fairly well shown in Figs. 8 and 9, Plate XXIII., and Fig. 13, Plate XXIV. It also appears in Figs. 6, 10, and 4, but is in these views partially obscured by the steelwork of the bridge. The traveller was designed to pass between the main trusses of the bridge, and much care was taken to arrange matters so that its use should interfere as little as possible with the fixing of the bracing between these two main trusses. As seen in the views above referred to, the traveller was mounted on six-wheeled bogies running on two 2-rail tracks, 54 ft. centre to centre, fixed at the ordinary floor level of the bridge. The two inner rails were carried on

* See ENGINEERING, vol. lxxx, page 376.

† See ENGINEERING, vol. lxxxiv, pp. 329, 351, 388, 391, 401, 418, 449, 470, 494, and 815; also vol. lxxxv, pp. 346, 405, 412, and 580.

‡ See ENGINEERING, vol. xci, pp. 369 and 761; vol. xcii, page 769; vol. xcviii, page 349; vol. cii, pp. 259, 304, 336, 364, 416, 441, and 463; and vol. civ, pp. 404 and 438.

* See ENGINEERING, vol. xcviii, page 349.

THE NEW QUEBEC BRIDGE.

(*For Description, see Page* 277.)

Fig. 14. Main Blocks and Tackle of Traveller.

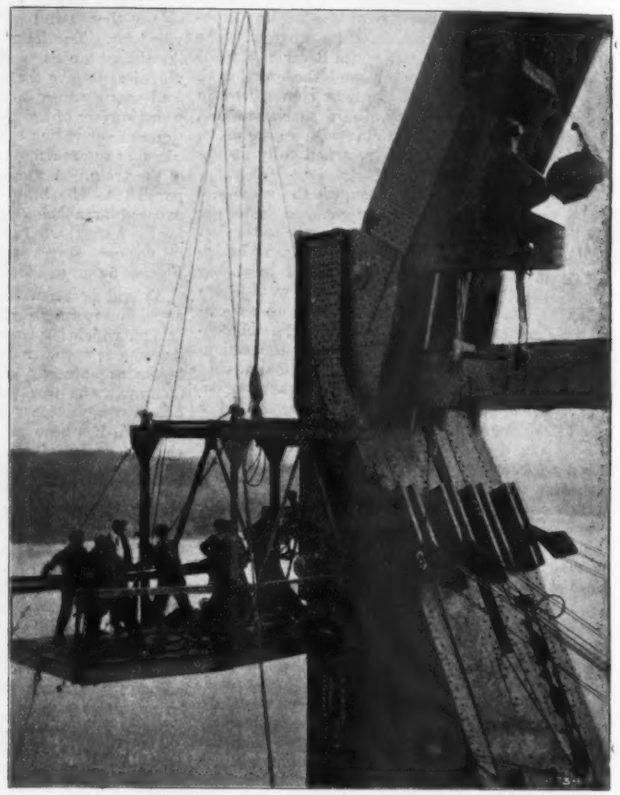


Fig. 15. Driving a Pin at Junction of K Bracing.

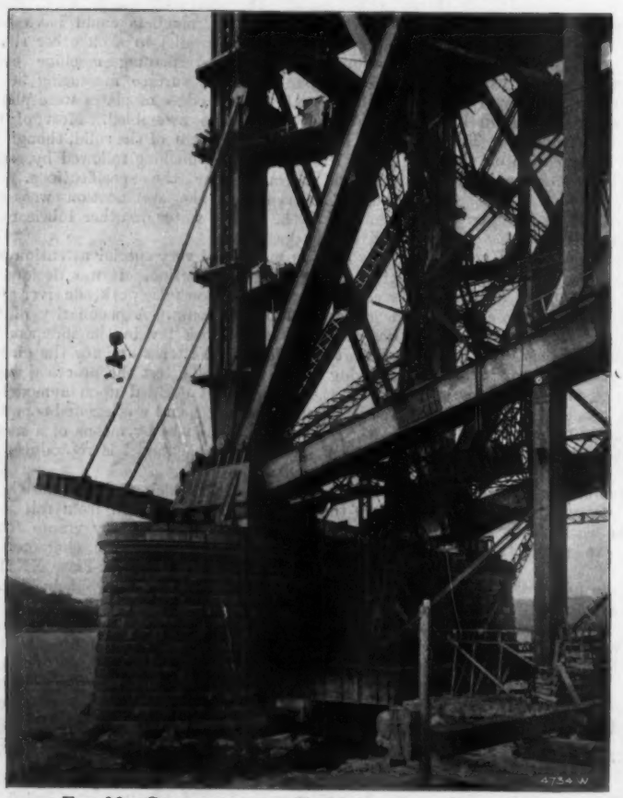


Fig. 16. Commencing the Erection of the River Span showing Flying Bridge in Place.

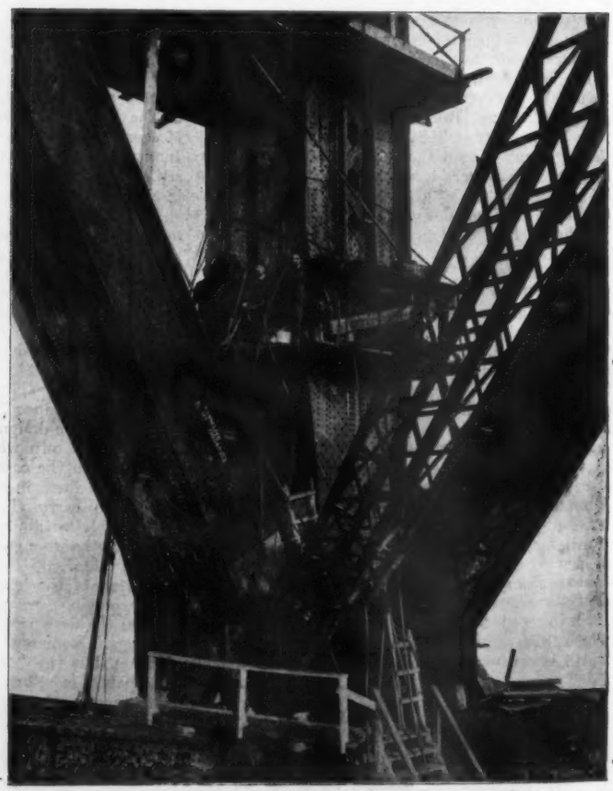


Fig. 17. Junctions of Diagonals at Foot of Main Vertical.

THE NEW QUEBEC BRIDGE.

(*For Description, see Page* 277.)

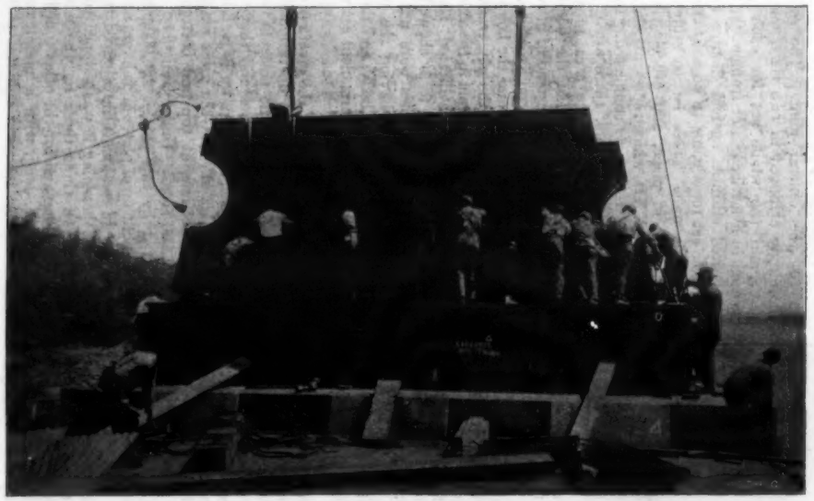


FIG. 18. MAIN SHOE IN COURSE OF ERECTION.

FIG. 19. VIEW OF PIER WITH MAIN SHOES IN PLACE.

FIG. 20. ERECTING ONE OF THE MAIN PINS.

FIG. 21. VIEW SHOWING THE TWO COMPONENTS OF A MAIN PIN IN PLACE.

the top flanges of the outer floor longitudinals of the bridge and the two outer rails on special erection girders, which are fairly clear in Figs. 8 and 9. Provision was also made by which, when engaged in the actual work of erection, the whole of the weight of the traveller and its load was taken off the bogies.

Two hoists running on rails laid on the upper level of the traveller were provided. These were electrically driven and were each capable of lifting 110 tons at an overhang of 35 ft. and had an out-to-out reach, transverse to the bridge, of 47 ft. on each side of the centre line. These cranes were controlled wholly from a cabin near the bottom of the traveller.

A view of the main sheave of the tackle is reproduced in Fig. 14, on page 278. This view also shows the attachment used in hoisting plate girders. As will be seen, there are four hooks which fit over the flange and hold the plate securely without the aid of ropes.

In addition, the traveller was fitted with four derrick masts, one at each corner, as is well shown in Fig. 13, Plate XX, which represents the traveller engaged in the erection of the false work for the anchor arm span. These derricks were each capable of carrying a load of 20 tons at an overhang of 90 ft., and were also operated electrically. Lighter lifting tackle for general use was, of course, also provided.

The first operation to which this traveller was applied was the erection of the "inside" false work. At the same time the main floor beams were put in place and the special temporary track girders for the outer traveller rails. The work was started at the main bridge abutment (see Fig. 13, Plate XXIV), and when the traveller reached the pier, it erected on the latter the main shoe. This stage of the work is represented by the views given in Figs. 18 to 21, on page 279.

Each main shoe was built up in three stages. The lower consists of four steel castings, measuring each 20 ft. 10 in. by 6 ft. 8 in. by 4 ft. in height. The scantlings of these castings range in thickness from 2¾ in. to 3 in. and the weight of each casting is about 40 tons. The four components are held together by 2½-in. bolts, and secured to the pier by twenty-eight 3-in. anchor bolts through the extreme flanges and by sixteen 3-in. steel dowels secured to the interior of the castings. The former are sunk 5 ft. into the masonry and the latter 6 ft. The interior of these castings was filled up with concrete after the erection of the second tier of the shoe. This second tier transfers to the lowest tier the loads due to the weight of the bridge and to the wind. The former amounts to about 45,000,000 lb., and the maximum wind load is estimated at 6,200,000 lb. The average stress on the masonry is 660 lb. per sq. in., and the maximum 915 lb.

The second tier of the shoe, as is well seen in Figs. 18 and 20, page 279, is built up of steel plates —stitch-riveted together. There are four webs, which match the webs in the main compression members of the cantilever, and these four webs are, of course, rigidly braced together by all necessary diaphragm plates.

The main pins through which the cantilever arms transmit their thrust to the shoe are 30 in. in diameter, but in order to increase the bearing surface on the webs of the shoe and lower chord member, the pins are bushed as indicated in Fig. 22, annexed. This bushing is a steel casting with an outer diameter of 45 in.

To facilitate handling, two pins are used at each shoe to take the thrust instead of one. This is shown in Fig. 21, but, nevertheless, each section of the pin weighs over 6 tons. The top stage of each shoe is also built up of steel plates. It receives the thrust of the main vertical over the pier and of the main diagonals of the web bracing. The joints at this point are illustrated in Fig. 17, page 278, which shows the junctions at the foot of one of the main verticals.

An excellent idea of the enormous proportions of these main shoes is afforded by Fig. 20, on page 279, whilst Fig. 19 shows the two shoes in place on the pier, ready for beginning the erection of the anchorage arms. This section of the work was started at the main pier, and the material erected was supported on outside false work independent of that used for supporting the traveller and the flooring of the bridge.

We have already described the way in which the bottom chords were built up and a view taken during the erection of the first element of these chords is reproduced in Fig. 24, page 290, whilst Fig. 8, Plate XXIII shows the erection of the lower chord completed. Other views illustrating the erection of this shore span, at various stages, are reproduced in Figs. 9 and 10, Plate XXIII, and Fig. 5, Plate XXII, where the work in hand is the erection of the main vertical. Note should be taken of the independent inside false work supporting the floor members of the bridge and the temporary traveller tracks.

To ensure that the lower chord should be straight under the designed bridge loading its deformation

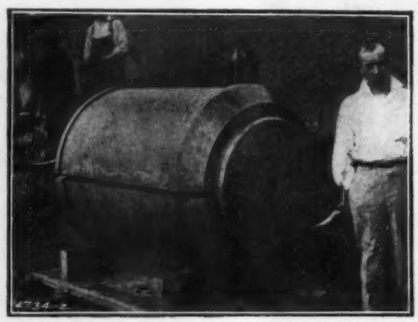


FIG. 22. MAIN PIN AND BUSH.

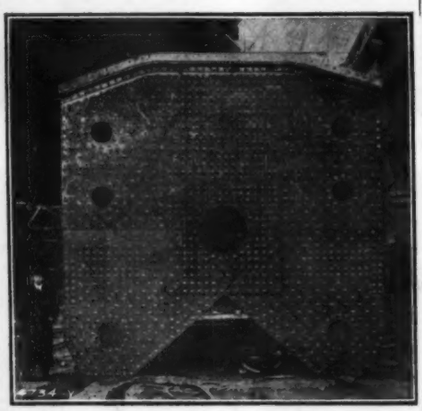


FIG. 23. JUNCTION PIECE AT TOP OF MAIN VERTICAL.

under this was computed, and after it had been erected complete as indicated in Fig. 8 the whole chord was lowered at each point of support by amounts numerically equal but of opposite sign to the above computed deflections. The maximum deflection needed at any point was 7 in.

Every compression member was finished just so much longer than its nominal length that it would have accurately its nominal dimension when the bridge was fully loaded. Similarly, tension members were made, so that when unloaded they were a little shorter than their nominal length, but would acquire these nominal lengths when under the full bridge load. As a consequence of these precautions, the structure is almost free from secondary stresses when fully loaded, although when unloaded, the secondary stresses are considerable, but the primary stresses are then reduced, so that the combined primary and secondary stress is, in general, less than the maximum stress to which any component is subjected.

Having completed the erection of the lower chord members, the traveller was moved back again to the main pier and the work of erecting the web members commenced. This was effected in two stages, the lower halves being first erected up the middle joints of the K bracing, as indicated in Fig. 9. To facilitate erection and to provide for the deformation of these large members under their own weights the pinholes were elongated, and as a consequence the work of assemblage and driving the pins proved extremely easy. It has been already mentioned that the pins do not pass through the webs of the lower chord, but through gusset plates riveted to these chords. Each web member makes, therefore, connection with this lower chord by means of a separate pin, but these are, of course, so located that the lines of stress of all the members at a joint intersect in the same point, thus avoiding local bending actions.

The floor beams are heavy plate girders 88 ft. long and weigh some 50 to 60 tons each. In the case of those supported by the main verticals of the truss these girders have double webs and are 10 ft. deep over angles. Single webs are used for the intermediate beams, and these are 11 ft. 3 in. deep over angles. In general, these floor girders are connected to the truss verticals by 11-in. pins, but rigid connections are used for the two beams at the outer end of the cantilever arm. The pin joints, used elsewhere, were adopted mainly with a view of facilitating erection, but also in part with the intention of eliminating the secondary stresses which rigid connection would generate in the truss verticals.

The completion of the second stage of the operation is represented in Fig. 8. The anchor bars were next put in place. A view of these is given in Fig. 12, Plate XXIV. The traveller next worked back to the river pier, completing, stage by stage, each panel behind it. This operation is illustrated in Fig. 8. The tension diagonals of the web were very long, and many of them had to be shipped in two pieces. Though tension members, they are rigid, riveted structures, capable of resisting without material deformation considerable transverse forces, whether due to their own weight or to extraneous sources. It had originally been intended to use a similar type of structure for the upper tension chords of the cantilevers, but it was ultimately decided to construct these as eyebars. The panel length was, however, too great to be spanned by a single eye bar—two being necessary. It was, however, considered desirable to eliminate the flexure naturally due to the central joint. The eyebars were accordingly arranged in two tiers, one above the other, and the whole set for each panel were enclosed in a lattice girder framework, which gave the desired stiffness against flexure and enabled the whole set for a panel to be hoisted and erected as a single unit. These lattice stiffeners remain permanently in place, and are clearly visible in Fig. 5, Plate XXII, which represents the anchor arm when erection was nearly completed. In the panels adjoining the main piers, there are 32 bars 16 in. wide by $2\frac{3}{16}$ in. thick, the area provided being therefore, 1,120 sq. in. Had the whole set been arranged in a single layer instead of in two tiers the overall width would have been excessive. The pins used are 14 in. in diameter and the holes in the eyebars are $\frac{1}{32}$ in. larger than the pin, tranverse to the bar and $\frac{1}{4}$ in. larger than the pin in the axial direction. This provision greatly facilitated the work of erection, and comparative tests showed that bars with these "ovalised" holes were not inferior in strength to similar bars having the usual round hole. Both broke in the body, and the differences in the deformation and permanent set were immaterial.

The next operation was the erection of the main posts over the piers. This operation is illustrated in Fig. 5, Plate XXII. The posts have a length of 310 ft. between pin centres and the cross-section, measures over all, 9 ft. 2 in. by 10 ft. 2 in. The net area is 1,903 sq. in., and the gross weight inclusive of the connections at top and bottom of each is about 1,200 tons. Under full load the thrust transmitted by this part is 266,000,000 lb. Each post was built up of plates and shapes and consists of four heavy H-sections firmly braced together, and to facilitate handling it was shipped to the site in 26 pieces. Of these those for the middle section were 36 ft. long and for the other four intermediate sections 55 ft. long, with a maximum weight of 120,000 lb. At its lower end this post rests on a 45 in. bushing surrounding a 30 in. pin at the top of the main shoe. At the top two members are con-

nected up with the post on each side, viz., the main diagonals and the upper chords. A view of the connecting piece is given in Fig. 23, page 278. This component is the heaviest unit in the bridge, and had to be shipped in two sections, each of which weighed 65 tons.

The channel cantilevers were erected by building out, and this work was greatly facilitated by the adoption of the K system of bracing. With this the maximum over-hang required from the traveller was 42 ft., or one sub-panel of the bridge, and as the cross bracing between the two main trusses could be erected immediately behind the traveller tower, the rigidity of the structure could be well maintained throughout the whole process of erection. Different stages of this work are represented in Fig. 4, Plate XXII., and Fig. 11, Plate XXIV.

As already mentioned, the lower chord members near the pier were too heavy to be handled in one piece and were accordingly erected in four pieces, which were spliced together *in situ*. In the case of the anchor span, the use of false work made this operation easy, but for the river arm which was built out, other arrangements were necessary. The plan adopted was to suspend a temporary "flying bridge" underneath the member to be erected. This is represented in Fig. 16, page 278, and Figs. 26 and 27, page 290. In Fig. 26 half the chord member is shown in place, resting on this flying bridge, which extended across the whole width of the structure as indicated in the figure.

A still later stage in the erection of this lower chord member is represented in Fig. 25, which also shows the splice plate for the diagonal and vertical web members. When the latter had been erected, the chord member became self-supporting and the flying bridge was moved forward ready for the erection of the next chord section. These vertical members were pin-connected to the chord at the bottom and to the middle joint of the K at the top. The driving of the pin at such a joint is illustrated in Fig. 15, page 278.

The central span, which is 640 ft. long between centres of main pins, was erected on piling driven into shallow water a few miles below the bridge site. It was floated off this staging by barges and towed up-stream to the bridge and then lifted into place by chains operated by hydraulic jacks. As will be remembered, in a first attempt to effect this lifting operation a flawed casting used to support one corner of the span failed and precipitated the whole into the river. A full description of this accident and of the method of erection was given in ENGINEERING, September 15, 1916 and October 6, 1916. It was impossible to salve any portion of the sunken steelwork, and an entirely new span had to be constructed. This was erected according to the original plans last year (see ENGINEERING, vol. civ, pp. 404 and 438), and the completed structure is, as we stated at the commencement of this article, represented in Fig. 1, Plate XXI., whilst Fig. 2, on the same plate, shows the test load which was run over the bridge on August 21 last. The total weight of the two trains, which were allowed to rest on the bridge for 2 hours, was 14,000,000 lb. We heartily congratulate all concerned on the completion of this great enterprise.

PAYMENT BY RESULTS.

By D. LYON MCLARTY.

THE war has brought the importance of payment by results into a prominent position. Its general adoption has been strongly recommended by the Government, including an influential labour leader. It is recognised that if it could be generally applied in a form which met with the approval of both employer and workman a tremendous improvement in output, reduction in cost and increase in wages would be effected, and that, both with regard to present and post-war conditions, it is a matter of outstanding moment. Yet, its progress has been negligible. This is mainly due to the fact that the systems so far adopted have, either owing to inherent defects or on account of having in some cases been applied in an unsympathetic and short-sighted manner, caused a certain amount of dissatisfaction among the workmen sufficient to induce the opposition of the trades unions to their further adoption.

Regarding the two better known and more operated systems, i.e., piecework and premium bonus, the writer is convinced that a lack of adaptability in the former and a want of complete understanding of the underlying principles of the latter are the main causes of their incomplete success. Piecework, except in the case of simple operations and large numbers of similar articles, is incapable of being successfully applied to shipbuilding and engineering generally. The Walton system of collective piecework, very successful and ideal in its effect regarding shell and similar repetition work where the output over a short period is accurately determinable, also lacks practical application to shipbuilding and engineering generally.

The one system so far introduced which contains all the elements necessary to successful and sympathetic application to the variations of these trades is the premium bonus system, and it is regrettable that it should have been handicapped by mishandling. There has been too little thought and care given to the time setting, which in turn paved the way to that confidence-destroying mistake of "rate-cutting," to which latter the writer chiefly attributes any distrust of and opposition to the premium bonus system which has arisen in some quarters.

If the progress that is so much called for is to be made, it is essential that the workmen should be shown that the objections they have to the system are due, not to the system itself, but to the manner in which it has been operated in some cases, and that both they and their employers should have a fuller understanding of the application of certain of its features, neglect of which inevitably acts against, and observance of which mutually benefits both parties. It is hoped that the following notes will show that the premium bonus system is capable of ideal application, and, properly handled, of automatically safeguarding the interests of workman and employer alike.

While the statements which follow are true of any form of premium bonus, for the purpose of illustration, examples are given worked on the Rowan premium bonus system, which has proved so successful where it was originated and in which the division of saving in labour cost effected appeals to the writer as being very fair and self-adjusting in a manner which would be difficult to excel. Sir William Rowan Thomson has described this system fully in his book on the subject, and for the purposes of this article it is only necessary to comment on the division in labour cost effected.

Under the Rowan system the workman receives as a bonus the same proportion of hours to the time taken as the time saved bears to the time allowed. That is to say, if a man is allowed 100 hours in which to do a job and takes 75 hours, he, having saved 25 per cent. of the time allowed, receives as a bonus 25 per cent. of 75, which is 18¾ hours, his total wages for the job being 75 plus 18¾ hours at his time rate. This leaves 6¼ hours of the time saved to his employer, which is a proportion of three to one in favour of the workman. Below 25 per cent. saving of the time allowed the proportion increasingly favours the workman, while above 25 per cent. it decreasingly continues in his favour until it reaches 50 per cent., where the division is equal, after which the proportion is increasingly in favour of the employer. At the same time the workman's actual bonus always increases in exact proportion to the time saved.

Many workmen are confused on this point, and it should be made clear. Take a time allowance of 100 hours. If a man saves 25 hours, he has worked 75 hours, and his bonus is 18¾ hours, which, to bring it to a common basis for comparison, is equivalent to 25 hours bonus for 100 hours' work—his employer's saving being 6¼ hours. If he saves 50 hours, he has worked 50 hours, and his bonus is 25 hours, which is equivalent to 50 hours' bonus for 100 hours' work—his employers saving being 25 hours. If he saves 75 hours he has worked 25 hours, and his bonus is 18¾ hours, which is equivalent to 75 hours bonus for 100 hours' work—the employer's saving being 56¼ hours. So that the workman's bonus increases in direct proportion to his efforts, while, as regards the time saved, the workman is increasingly favoured below 50 per cent., and above 50 per cent. the employer is increasingly favoured.

It is an excellent division because the workman, in a case where he feels that the time allowed is rather little, can still work with a will knowing that he will be somewhat compensated by his consequent smaller saving bringing him a larger proportion of the time saved, while on the other hand the employer need not hesitate to allow additional time in case of doubt because he is similarly partially compensated by the consequent larger saving bringing him a larger proportion of the time saved. Also as the average amount of time a man can save without unduly exerting himself is below 50 per cent., anything above that is due to an over generous time allowance, and therefore the fact that a greater proportion over 50 per cent. goes to the employer is only just and, as will be seen later, it protects the workman from rate-cutting.

There is an impression among some workmen that the employer should not share in the saving in labour cost effected at all, and they hold that the saving in on-cost should be a sufficient reward. The fallacy of this becomes apparent when the principle of the system is understood, and instead we find that before the system becomes of real value to the workman, the employer must have a proportion of the saving (over and above his working expenses) sufficient to make him directly interested in the workman's bonus, without which margin he cannot be expected to work the system in the necessary free manner. This is quite apart from the advisability of the employer being in a position to reduce his selling price, thus improving his position as regards competition and obtaining more orders to the mutual benefit of himself and his workers, which is now generally recognised as sound trade economics.

It cannot be too strongly emphasised that the fact that under the premium bonus system the employer shares in the saving in the labour cost is the strongest point in the workman's favour. If the employer's only reward was the somewhat intangible reduction in on-cost, then even the most prejudiced must admit that—since it is unreasonable to expect an employer to introduce a system for increasing production which is going to cost more per job than the system in use upon which he wishes to improve—he cannot be expected to allow more time than it would take under ordinary working conditions. And, as in fixing a time allowance there are always a good many variables to take account of, it is impossible for anyone to set a time which is not liable to be from 1 hour to, say, 5 hours in question, according to the amount of work on the job, the employer must err on the safe side, and this lack of facility for adjustment would make the fixing of time allowances, in a way that would satisfy both sides, almost impossible.

But, if the employer does share in the saving, he can afford to err—to the extent of his saving without actually losing—on the generous side. More important still is the fact that if he is to benefit in proportion to the saving it pays the employer to increase the time allowance sufficiently to encourage a man to make good bonus, whereas, if the employer is not to share in the saving, as the labour cost will then always be the same, there is an inducement to cut the time allowance as closely as possible. The following example illustrates the foregoing remarks.

Take a job the time allowed for which is 100 hours. Assume that the workman was not satisfied that this was a fair allowance and saved only 15 hours, that job would cost the employer 85 hours time plus 12½ hours' bonus; a saving to him of 2½ hours. If, however, the man by being allowed 105 hours felt he was being well treated, worked with a will and saved what is a common proportion, say, 30 hours, the job costs the employer 75 hours' time and 21 hours' bonus; a saving to him of 4 hours, as against 2½ hours for the 100-hour allowance, while the workman receives a bonus of 21 hours for 75 hours' work, as against 12½ hours for 85 hours' work. But if the employer was not to share in the saving by allowing 105 hours, the job would cost him 5 hours more than by holding to the 100-hour allowance.

Anyone entrusted with the working of the bonus

system should realise the importance of erring on the generous side with the time allowances. This, unfortunately, has sometimes been forgotten, with disastrous results. There is nothing which will disgust a man, who is being asked to put forth extra effort, more than to feel that at the end of it he may find his return insufficient. It is imperative that he should feel certain that a fair return is secured. There is no excuse for niggardliness with time allowances. The system can produce the wherewithal to pay for generous working, the keynote of success is a feeling of confidence on the part of those who are being asked to put forth the extra effort, and if that feeling is not engendered and carefully maintained, dissatisfaction and loss will follow.

The fact that the employer shares in the saving has a further recommendation in that it makes rate-cutting unprofitable, and this can only have occurred where there was a lack of understanding of its detrimental effect. There is nothing that is more likely to kill the system and, as the following example shows, it is as harmful to the employer as it is unfair to the man. A temptation to cut a time allowance might occur where an excessive amount of money had been earned in a given period, creating the impression that the time allowance was too much. Now, if the employer did not share in the saving, a reduction on the time allowance would be a direct gain to him, but in premium bonus it is not. Take, again, the case of a time allowance of 100 hours, and suppose a man had done the job in 50 hours, that would cost the employer 50 hours' time and 25 hours' bonus—a total of 75 hours. If the allowance was cut to 90 hours, and the man still did the job in 50 hours, the cost would be 50 hours' time plus 22½ hours' bonus—a total of 72½ hours, making a saving to the employer of 2½ hours for a 10-hour reduction.

But—and this is the point—if the man, as would be natural, resented the reduction, he would not work so keenly, and if he took as little as 5 hours longer (did the job in 55 hours), he would receive 55 hours' time plus 21½ hours' bonus—a total of 76½ hours, thus costing the employer at the 90-hour allowance 1½ hours more than it did on the 100-hour allowance. Further, if the man felt that rate-cutting was to follow a large saving in time, he would take good care to keep within safe limits, say 25 per cent., in which case the job would cost the employer 9 hours more than on the original allowance of 100 hours. As this would apply to all workers it is easy to see that rate-cutting, and its consequent destruction of the men's confidence, does not pay the employer if he has a share in the saving in labour cost. If, however, he was not to participate in the saving in labour cost, by cutting the time allowance to 90 hours, he would save 10 hours. From these facts it is surely clear that it is to the best interests of both sides that the employer should have a share in the saving effected in labour cost, over and above the on-cost and running expenses of the system.

A point on which the Employers' Federation and the trades union have been unable to agree is the method of fixing the rates or time allowances. The men, naturally, from their point of view, wish to have a say in the matter, while the employers, convinced of their desire and ability to adjust things fairly, reasonably object to surrendering their rights in the question and thus pave the way to endless discussions. This important point could be completely met by the following provision :—

The rates or time allowances to be fixed by the employer, but the employee, if not satisfied, with an unestablished rate, to be free to work on ordinary time conditions, and the employer also to be free to have the job done on time conditions if he so desires. This inevitably safeguards both parties. The only justification there is for asking a man to work harder than he does on fair time conditions is that he will benefit sufficiently in return. If the time allowance for any job fixed by the employer does not offer sufficient inducement to a man to work harder, he can do the job on time conditions, and neither party is worse off than before. If the employer feels able to increase the allowance (and it should be easy for him to know) he can do so and, in a genuine case, both will benefit.

It may be argued that this is an inducement to the man to work on time conditions in the hope that his allowance will be increased, but (ignoring the fact that the employer should be able to tell, within safe limits, whether the time allowed is sufficient or not) assuming that the allowance was increased to a greater degree than was necessary, the employer is amply protected. If the man worked things so that he merely made a small saving on his increased allowance in the hope of justifying it, he could be told that he either saved a larger percentage (sufficient to make it a paying proposition) or that he would have to do the job on time conditions in future. There is a sprinkling of dead lazy men about, but the large majority are willing to work for a fair return and incidentally prove their ability. Thus the matter would adjust itself in due course, the worst conditions possible being that the job would be done on ordinary time conditions. This freedom on either side is important and covers any form of injustice or error. It is a final answer to any argument that might be raised against the premium bonus system, because it puts both parties in a position of absolute security.

The more one studies the system, the more ideal its properties become. There is no objection which can be raised against it which cannot be directly met, except one which could be applied to any form of payment by results, or indeed any improvement. It is to the effect that the accelerated production will do men out of a job, a shortsighted theory which, under ordinary conditions, can only be met on broad economic lines, but which, under present conditions, is no reason at all.

At the present time when the work a firm can get is restricted only by the amount it can do, when ships are wanted, and will be wanted for years to come, more rapidly than they can be built, when foreign builders advertise in British journals their anxiety to build for British owners, and everything points to the imperative need of Britain doing all she can to keep her end up in commerce and in war, any such argument is futile. Men are more likely to lose work by refraining from doing that which will keep the work in their own country.

Shipbuilding and engineering are of vital importance. All the organising, standardising and controlling in the world are of comparatively little use in increasing production unless the workmen concerned will put forth the requisite extra effort. The premium bonus system, properly handled, can induce and proportionately reward that extra effort on both sides in an ideal and safe manner. It is time the Government took definite steps in the matter, and insisted on the system being put in operation wherever time conditions at present exist, for the period of the war. If the method of fixing rates indicated in the foregoing be adopted there can be no excuse for either party refusing. The large majority of the workmen of the country are good living, fair-minded men, and, the Government being in a position to carry the trades unions with them, will give it a fair field. It will then be up to the employers to justify the system for their country's, their workmen's, and their own sakes, to the confusion of the present submarine menace and to the strengthening of Britain's hand in the commercial war that is bound to come.

ABBE AND PULFRISH REFRACTOMETERS.

CONSTRUCTED BY MESSRS. ADAM HILGER, LIMITED, LONDON.

FIG. 1.

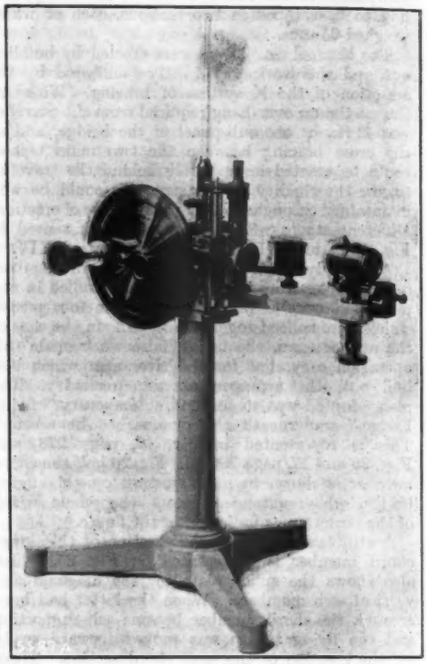


FIG. 2.

THE ABBE AND PULFRISH REFRACTOMETERS.

THE two refractometers, which we illustrate in Figs. 1 and 2, above, are of new types constructed by Messrs. Adam Hilger, Limited, and formed part of the exhibits of the firm at the British Scientific Products Exhibition which was closed last week.

The Abbe refractometer, Fig. 1, designed for the accurate and rapid determination of the refractive index of a liquid (or also a solid), to the third or fourth decimals within the range 1. 3 to 1. 7, is a direct reading instrument and requires very little of the substance. In the case of a liquid, which may be turbid or coloured, or of a wax, which is melted in the apparatus, a thin film of the substance is spread on the common surface of two superposed prisms. By the aid of an attachment to the telescope daylight or artificial light may be used, and with the help of a circular scale on this attachment, the dispersion (i.e., the difference of the refractive indices for the C and F lines of the hydrogen spectrum) can be determined from tables supplied with the instrument. Two dense-flint prisms of 60 deg. contain the film in question between their opposed hypotenuse faces; the upper prism has this face polished, and it is the critical edge for the total reflection of the light, that has passed through the substance examined (the film) and this prism, which is set on the cross lines in the telescope. The corresponding face of the lower prism is greyed to prevent the formation of false images, the prism itself serving to introduce the light into the liquid film. The prisms are mounted in a water jacket, and by means of a thermostat constancy of temperature is maintained, this being necessary, not only because the refractive index of liquids changes rapidly with temperature, but also because any wax to be studied has to be melted

at a definite temperature. The water jacket is attached to a radial index arm, which is hinged about a horizontal axis and is fitted with a lens and index moving over the graduated arc, on which three decimals can be read and the fourth decimal can be estimated. The telescope and achromatising attachment are fixed to the sector, and the whole system (telescope, prisms, index arm and sector) is hinged about a horizontal axis; this arrangement is convenient for cleaning the prisms and applying the film, and facilitates the examination of solids. A solid to be examined is provided with a plane surface and attached to the refracting prism by means of a fluid medium having a higher refractive index than the substance. The optical particulars of the dense flints must be known with considerable precision, and sensitive tests have to be conducted to ensure, that all the glass of one particular batch is of identical properties, and that the prism angles are identical, so that a prism may be replaced by another in cases of accident or of severe wear. The achromatising devices and the preparation of the tables call for the same care and scientific skill, features as to which the reputation of Messrs. A. Hilger offers a sufficient guarantee. When this instrument is to be used in the sugar industry, it is supplied with an additional scale giving directly the percentage of "dry substance" at the standard temperatures of 20 deg. or 28 deg. C.

The Pulfrish refractometer has, owing to the ease and accuracy with which measurements of refraction and disperaion can be made comparable to spectrometer methods, become the favourite instrument for determining the optical constants of glasses except in very special cases. Our illustration, Fig. 2, shows the improved design of Messrs. Hilger. A prism, exactly right-angled and of known optical density, is so mounted that one face is horizontal and the edge of the right angle parallel to the axis of rotation of the divided circle carrying the telescope. The specimen under investigation is placed on the horizontal face or, in the case of a liquid, in a shallow glass cell cemented to the top of the prism. A beam of monochromatic light is passed almost horizontally through the specimen so as to graze the prism face; the ray corresponding to the critical angle on emerging from the vertical plane face is observed with the telescope and measured, by means of a vernier, to half a minute of arc. With the aid of a clamp and micrometer differences in the angle of emergence of two spectral lines are measured within 0.1 minute of arc, and the dispersion is thus determined. Other parts of the instruments are a condensing lens and a supporting rod for the vacuum tube giving the comparison spectrum; by the help of a small reflecting prism a sodium flame or other source of light may be used in the place of the vacuum tube.

One of the modifications of the latest design concerns the micrometer attachment. The arm which clamps the circle and the clamping device are so made that the micrometer readings are accurate without requiring the aid of a correction curve over the long range of glass-testing. Each of the prisms is mounted in a water jacket through which water is made to circulate at a definite temperature. Another water jacket can be placed over the top of the prism so that only the vertical face is left free, as it must be; this water jacket is secured to the base of the instrument by a clamp screw fitted with a large milled head so constructed that the jacket automatically assumes its correct position as the screw is tightened. A further point is the improved object in the focal plane, both for setting on the critical edge in the field and for adjusting the zero, that is, obtaining accurately the circle reading corresponding to the normal and the vertical face of the prism. If μ_0 be the refractive index of the prism, μ that of the specimen and i the angle of emergence, then $\mu = \sqrt{\mu_0^2 - 2\sin^2 i}$; the values are read off from tables supplied with the instrument which is of course, as rigorously tested as the Abbe refractometer.

THE EFFECT OF COLD WORK ON COPPER.

*The Effect of Progressive Cold Work upon the Tensile Properties of Pure Copper.**

By W. E. ALKINS, B.Sc., Student Member (Manchester).

Introduction.—It has long been known that when the majority of metals are submitted to cold work, by hammering, forging, drawing through dies, and so on, their physical and mechanical properties are affected; thus, the density decreases, the tensile strength increases, the ductility and electrical conductivity decreases, &c. To explain this "hardening by plastic deformation," as it is called, various theories have been put forward, *e.g.*, the amorphous phase theory of Beilby, Rosenhain, and others, the inter-strain theory of McCance, &c. None of these theories is wholly satisfactory, probably because each is founded on work which is qualitative only. Few, if any, attempts have hitherto been made to discover whether any quantitative relationship exists between the amount of cold work done upon the metal and the magnitude of the change in its properties. In the present paper an account is given of an inquiry into the change in tensile strength of copper in the form of wire as it is progressively hardened by cold drawing in the ordinary way.

Choice of Metal.—It is not permissible to assume that the phenomena of hardening by plastic deformation will be exactly the same in the case of both pure metals and metallic alloys; and it will be sufficiently obvious that the simpler the metallic system investigated, the greater the likelihood of gaining an insight into the process of the hardening.

Copper was chosen as the experimental material for three reasons: (1) it appeared to afford an example of a simple metallic system, which undergoes no definite thermal change between its melting point and the ordinary temperature (compare, however, the recent work of Cohen, who, from dilatometric observations, argues in favour of the existence of an allotropic modification of copper with a transition point at about 70 deg. C.; this will be discussed in the sequel); (2) copper shows the hardening by plastic deformation very well: thus, its tensile strength may be doubled by hard-drawing, and the metal will not yet show any indication that it is overdrawn; finally, (3) through the generosity of Mr. M. A. Bolton, of Messrs. Thomas Bolton and Sons, Limited, Oakamoor, it was most readily obtainable by the author of sufficient purity* and in the required form.

Previous Work.—Earlier experiments have been carried out by Mr. Thomas Bolton† and by Mr. D. R. Pye.‡ From a study of the results obtained by Mr. Bolton, Mr. A. P. Trotter, electrical adviser to the Board of Trade, concluded that there was a linear relation between the tensile strength and the diameter, and suggested that the tensile strength might be expressed by a formula of the type:

$$T = a - bD.$$

where

T = tensile strength in tons per square inch.
D = diameter in inches, and a and b are constants.

Mr. Pye§ adopted this type of formula, defining hard-drawn copper wire as having "in no case . . . . a breaking strength of less than that given by the formula:

$$T = 30 - 20\,D."$$

Mr. Pye obtained his wire from various manufacturers, and did not attempt to trace any connection between its previous history and its tensile strength. The aim of all three observers appears to have been to lay down a trade definition or standard for hard-drawn copper, and the wire used by Mr. Pye was almost certainly not taken from the same sample of metal at successive stages in the drawing. Yet the latter makes his formula the basis for the suggestion that the increase in tensile strength is due to skin-hardening.

He suggests‖ that the reason why the tensile strength is a linear function of the diameter—and therefore of the circumference—is to be sought in the process of manufacture. "Hard-drawn copper," he says, "is forced through dies of progressively smaller size: during this process the outer skin loses its plasticity, becoming hard and of great tensile strength. This hardening is confined to the surface layers, and subsequently the effective strength of the whole wire is due to this circumferential hard skin, and becomes proportional to the length of the circumference."

This suggestion Mr. Bolton was unable to accept. He quoted an experiment in which "a piece of 0.5 in. trolley wire was first tested as drawn and then turned down in a lathe and tested at various stages of reduction. Another portion of the same wire was drawn down to similar sizes and tested." The results "were not quite consistent, and the experiment might be worth repeating, but they tended to show that the 0.5 in. wire as originally drawn was really harder in the centre than the outside."

It appears, however, that the formula,

$$T = a - bD.$$

is not capable of the interpretation put forward by Mr. Pye. It follows from the suggestion of the latter that the actual tensile strength ($T\,a$) of a wire of diameter $2r$ should be the sum of two amounts, one depending on the cross-sectional area (πr^2) and the other on the circumference ($2\pi r$). If, then, we assume that for each square inch of area we have a tensile strength of c tons, and for each inch of circumference a further tensile strength of c_1 tons, we have:

$$T\,a = \pi r^2 c + 2\pi r c_1.$$

Calculating this in tons per square inch:

$$T = \frac{\pi r^2 c + 2\pi r c_1}{\pi r^2} = r + \frac{2c_1}{r}.$$

Thus, for a wire of diameter 0.5 in.,

$$T_{0.5} = c + 8c_1;$$

and, for a wire of diameter 0.25 in.,

$$T_{0.25} = c + 16\,c_1.$$

But from the formula:

$$T = a - bD,$$

for a wire of diameter 0.5 in.

$$T_{0.5} = a - \tfrac{1}{2}b;$$

and for a wire of diameter 0.25 in.,

$$T_{0.25} = a - \tfrac{1}{4}b.$$

Thus,

$$c + 8c_1 = a - \tfrac{1}{2}b;$$

and

$$c + 16c_1 = a - \tfrac{1}{4}b.$$

Hence,

$$c = a - \frac{3b}{4};$$

$$c_1 = \frac{b}{32}.$$

Now, for a wire of diameter 0.125 in.,

$$T = c + 32c_1$$
$$= a + \frac{b}{4}.$$

Actually, however, from the formula

$$T = a - b\,D,$$

for a wire of diameter 0.125 in.,

$$T = a - \frac{b}{8}.$$

It may be objected that c would not remain constant; it must therefore be assumed to increase with diminishing diameter; the discrepancy between the two values for the tensile strength of $\frac{1}{4}$-in. wire is thus not removed, but is actually increased.

EXPERIMENTAL.

Drawing the Metal.—A billet of copper was cast and hot-rolled to $\frac{5}{16}$-in. diameter in the ordinary way. After rolling, the bolt was annealed for four hours at about 600 deg. C. to ensure the complete removal of stresses inside the metal, and allowed to cool slowly. It was then pickled in sulphuric acid to remove oxide scale, and was cold-drawn by light drafts down to 0.040 in. (one twenty-fifth, No. 19 S.W.G.) without any further annealing.

From the bolt after pickling and from the wire after each draft a few feet were scrapped from the end, and three 2-ft. lengths were cut for testing. The successive drafts corresponded to the successive sizes of the Imperial Wire Gauge, from No. 000000 down to No. 19, *i.e.*, 25 drafts in all.

Measurement of Diameter.—Diameters were measured with a micrometer screw-gauge of the Brown and Sharpe Manufacturing Company. Readings were made to 0.0001 (one ten-thousandth) in., six readings were taken from each wire, and the mean of these was taken as the actual diameter.

Tests.—The tensile strength of the wires was determined in the Whitworth Laboratories of the Victoria University of Manchester on a 5-ton Buckton machine reading to pounds. Five determinations were made, and these in every case concordant within 1 per cent.; the mean of the five was taken as the actual breaking load, and was converted into tons per square inch.

Results.—The results are shown in Table I below, and are plotted against diameter in Fig. 1, and against sectional area in Fig. 2, see page 284.

TABLE I—*Results of Tensile Tests.*

Series No.	Mean Diameter.	Sectional Area.	Tensile Strength.	
			Mean. Lb.	Tons per Sq. in.
	In.	Sq. in.		
0	0·553	0·24019	8,333	15·40
1	0·4653	0·17004	7,735	20·31
2	0·4328	0·14704	7,157	21·73
3	0·4015	0·12661	6,490	22·88
4	0·3730	0·10927	5,678	23·20
5	0·3487	0·095501	4,967	23·26
6	0·3242	0·082546	4,434	23·98
7	0·3014	0·071346	3,954	24·74
8	0·2748	0·059308	3,456	25·98
9	0·2530	0·050273	3,002	26·66
10	0·2325	0·042454	2,605	27·39
11	0·2134	0·035764	2,245	28·02
12	0·1919	0·028923	1,840	28·40
13	0·1767	0·024518	1,580	28·77
14	0·1610	0·020358	1,326	29·08
15	0·1450	0·016513	1,092	29·53
16	0·1284	0·012943	862	29·73
17	0·1160	0·010732	718	29·86
18	0·1049	0·0086450	582	30·05
19	0·0920	0·0066476	450	30·22
20	0·0798	0·0050013	340	30·35
21	0·0719	0·0040602	278	30·57
22	0·0648	0·0032980	227	30·73
23	0·0567	0·0025251	174	30·78
24	0·0488	0·0018704	129	30·79
25	0·0403	0·0012756	88	30·80

Obviously either of the curves (Figs. 1 and 2) may be obtained from the other; therefore it is of no importance which is selected for mathematical treatment. The curve of Fig. 2, which consists of two rectilinear portions united by a curve, will be further considered.

General Remarks.—While the experimental results give a smooth curve for the tensile strength against diameter or sectional area, they at the same time show conclusively that the effect of a certain amount of cold work at any stage is intimately connected with the previous history of the metal. Thus, there is one stage in the drawing at which a reduction of area of almost 10 per cent. (from 0.372 in. to 0.348 in. diameter) is accompanied by no change in tensile strength.

Analysis of the Curve Fig. 2.—The curve (Fig. 2)

* Paper read before the Institute of Metals, Tuesday, September 10, 1918.

* Determination of copper (with potassium iodide and sodium thiosulphate) gave the mean result 99.92 per cent., the remainder consisting of oxygen with a much smaller amount of arsenic.

† *Electrical Review*, January, 1907.

‡ Journal of the Institute of Metals, No. 2, 1911, vol. vi. page 165.

§ *Loc. cit.*

‖ *Loc. cit.*, page 176.

showing the variation of tensile strength with sectional area consists of two rectilinear portions, AV, CD, connected by a smooth curve BEC. This curved portion

Fig.1.

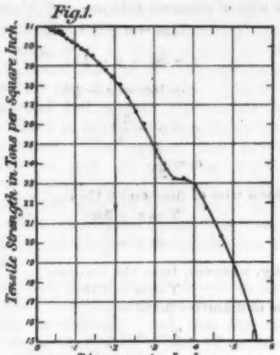
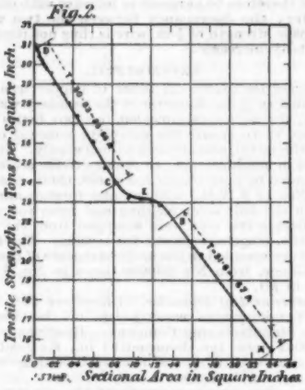


Fig.2.



shows only a point of inflexion at E, and not a maximum and minimum.

The portion AB corresponds to the equation :

$$T = 31.6 - 67A.$$

where

T = tensile strength in tons per square inch ;
A = cross-sectional area in square inches.

The upper rectilineal branch CD corresponds to the equation :

$$T = 30.83 - 82.66A.$$

The curved portion BEC agrees very closely with the expression :

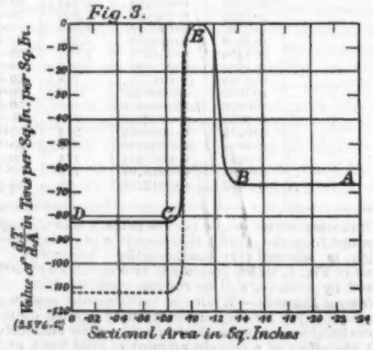
$$T = 23.2 - \sqrt[3]{A - 0.107},$$

but while the form of this portion is of the first importance, the corresponding mathematical function is only of secondary interest.

Significance of the Curve Fig. 2.—Differentiating the curve of Fig. 2 with respect to area (A), we have :

Over the portion AB, $\frac{dT}{dA} = -67$; from B to E the value of $\frac{dT}{dA}$ changes from − 67 at B to 0 at E ; from E to C the value of $\frac{dT}{dA}$ diminishes from 0 at E to − 82.66 at C, and over the branch CD, $\frac{dT}{dA} = -82.66$ (*cf.* Fig. 3, which is lettered to correspond with Fig. 2).

Fig.3.



Thus, from A to B the tensile strength increases at the rate of 67 tons per sq. in. for a reduction in area of 1 sq. in., while from C to D the rate of increase is 82.66 tons per square inch per square in. ; the rate diminishes from B to 0 at E, and increases again from E to C ; the curve shows no discontinuity, and at no stage is there a simultaneous diminution in sectional area and in tensile strength.

From the foregoing considerations it appears that in the drawing of copper the phenomena which present themselves are not of that simple nature which the amorphous theory would lead us to expect. That theory regards the process as continuous, in that further cold work always produces more amorphous material and gives therefore increased hardness. Yet we have seen that over a limited range reduction in area by cold work is accompanied by no change in tensile strength—and of this the amorphous theory, as at present interpreted, offers no explanation. It appears legitimate, in the absence of quantitative data, to assume that the amount of cold work actually performed on a metal during drawing is measured by the decrease in cross-sectional area : granting this assumption, we are forced to the conclusion that two distinct changes occur during the hard-drawing of copper, and that these two changes, which do not occur simultaneously, are taking place along the branches AE, ED respectively, of the curve of Fig. 2. Some further evidence in support of this view has been obtained, and will be brought forward later.

Investigation of Other Properties.—The variation of several other physical properties of the metal as it was drawn down was investigated, and such varied properties as density, elongation—both general and at fracture—scleroscope hardness, and so on, were all found to change in a similar way to tensile strength. Thus, for example, the density becomes constant over a limited range at 8.889, which corresponds to the specific volume 0.11251, the values for the annealed bolt being 8.9165 and 0.11214 respectively. In the case of every property investigated analogous results were obtained. It is intended that a full account of this and of further work shall form the subject of a subsequent paper.

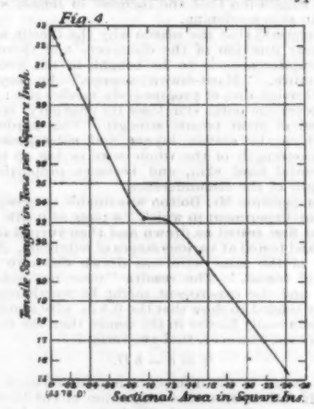
Suggested Explanation of the Observed Facts.—As a tentative explanation of the results recorded in the preceding paragraphs, it is suggested that :

When copper is subjected to cold work by drawing through dies, the first change which occurs is allotropic in nature ; after this change is complete, i.e., presumably, when the whole of the metal has undergone transformation a second change sets in, which may be regarded either as allotropic or as explicable on the lines of the amorphous theory ; of the two possibilities, the latter appears to be the more probable.

Additional Evidence.—In support of the above views the following additional evidence may be adduced :

1. A set of wires drawn down from the bolt by heavy instead of light drafting, the reduction in area, which in the case of the tests above described was accomplished in 25 stages, being effected by 13 operations, was tested, and it was found that the results obtained, which are shown in Table II below and plotted against area in Fig. 4 fell on a smooth curve of the same type as the

Fig. 4



curve of Fig. 2. Further, the values obtained coincided exactly with the curve of Fig. 2 over the range AE, which appears to show that the transformation occurring along that range is constant, and independent of the manner in which the cold work is applied. Beyond E, however, the new curve does not coincide with ED, but rises more steeply, the tensile strength corresponding to the 0.040 in. diameter wire being nearly 33 tons per square inch. This is well brought out on differentiation (Fig. 3, dotted curve). Thus the change which is taking place over the range ED would appear to be different in type from that occurring along AE.

TABLE II.—*Tensile Tests (Heavy Drafts).*

Series No.	Mean Diameter.	Sectional Area.	Tensile Strength.	
			Mean. Lb.	Tons per Sq. In.
	in.	sq. in.		
0	0·553	0·24019	8,333	15·49
1	0·4334	0·15096	7,270	21·50
2	0·3476	0·094896	4,932	23·20
3	0·2752	0·059482	3,504	26·30
4	0·2320	0·042310	2,680	28·28
5	0·1903	0·028442	1,898	29·79
6	0·1596	0·02006	1,380	30·79
7	0·1261	0·012489	882	31·52
8	0·0004	0·0079169	541	32·02
9	0·0820	0·0052810	383	32·38
10	0·0660	0·0034212	249	32·49
11	0·0547	0·0023500	172	32·68
12	0·0480	0·0018096	133	32·81
13	0·0397	0·0012350	91	32·82

2. Wires of such a diameter that they fall within the range AE are apparently stable at the ordinary temperature ; thus, after remaining for a year at room temperature they have undergone no perceptible change in tensile strength. They are, however, as is well known, not strictly stable, but rather metastable, as they anneal at temperatures of about 280 deg. C. and over, the tensile strength of the fully annealed wire being 15 tons to 16 tons per square inch.

On the other hand, wires corresponding with points on the branch ED are unstable at atmospheric temperature, their tensile strength undergoing a gradual reduction. The fall in tensile strength becomes more rapid as the temperature is raised, but no definite annealing temperature is observable ; this may be explained as due to the progressive diminution in viscosity with rising temperature, and supports the suggestion that the second transformation may be bound up with the formation of amorphous material. The spontaneous fall in tensile strength appears to cease when a value of about 23 tons per square inch—which corresponds to the stage E (Fig. 3)—has been reached. It is hoped that some indication may be obtained from tensile time observations with regard to the "order of reaction" of the change which is manifested by this fall in the ultimate stress.

It appeared at first sight that the phenomena above described, which present somewhat striking analogies with the behaviour shown by supersaturated (metastable) and labile (unstable) salt solutions, might be explained on the lines of the amorphous theory, on the assumption that, if the amount of amorphous material presented exceeded a certain critical percentage, spontaneous recrystallisation would occur. Thus, the stage E would correspond with this critical condition, and would be analogous with the limiting stage between metastable and unstable solutions. The difficulty in the way of accepting this suggestion lies in the form of the curve BEC, and in fact that the branch CD has a steeper slope than the branch AB, for there is no obvious reason why there should be a stage at which cold work does not lead to the formation of further amorphous material, yet beyond which the rate of production of the amorphous phase should be greater than the rate before that stage.

3. Finally, it has been found that if fully annealed wire of any diameter is taken and drawn down, a stage is always reached when the area of the wire has undergone a reduction of about 50 per cent., where, over a limited range, further drawing causes no corresponding alteration in properties. Moreover, the physical properties corresponding to this constant range are always the same, thus, the density is 8.889 ; the specific volume is 0.11251 ; the tensile strength is just over 23 tons per square inch, and so on. Hence, the point E (Fig. 2) appears to correspond with a definite physical state of the metal.

Bearing of the present Work on that of Cohen on the Allotropy of Copper.—The results which have been described above rather tend to support the views advanced by Cohen, which have been to some extent a subject of controversy.*

From dilatometric observations Cohen and Helderman conclude that copper undergoes an enantiotropic transformation (Cu α to Cu β as the temperature is raised) at about 71 deg. C. The change from Cu α, stable below 71 deg. C., to Cu β is accompanied by an increase in volume, and it appears that the observed phenomena would be explained by assuming this change to be in progress over the branch AE of the curve of Fig. 2.

Cohen and Helderman state that at ordinary temperatures copper ordinarily consists of a mixture of the α and β forms, of which the latter is slowly reverting to the more stable variety. That the β modification is present in hot-rolled copper would appear to be proved by the fact that immediately drawing begins the change proceeds at its maximum rate—there is no "period of induction" as there is in the case of the second change (EC. Fig. 2). Further, the rate of the reverse change in masses of the metal is so very slow that it is imperceptible after a year at the ordinary temperature.

Further experiments now in hand will perhaps throw more light on the whole question of the applicability or otherwise of the views of Cohen to the phenomena under investigation.

[*Note.*—It should be borne in mind that there is no experimental proof that an allotropic change *precedes* the formation of amorphous metal ; apparently the changes might occur in the reverse order, though this would involve the transformation of amorphous into crystalline metal by the action of cold work. In this connection it is worthy of note that amorphous copper itself must be regarded as an allotropic modification, and therefore to assume the amorphous theory of the hardening of metal is to postulate the occurrence of allotropy amongst the metals.]

Summary and Conclusion.—The following conclusion, then, may tentatively be drawn from the foregoing experiments :

The effect of progressive cold-drawing upon pure copper resolves itself into two distinct phenomena, which may perhaps best be regarded as an allotropic change followed by a second transformation, probably to be explained on the lines of the amorphous theory.

Finally, the author desire to express his cordial

* *Cf.* E. Cohen and W. D. Helderman, Proceedings of the Koninklijke Akademie van Westenschappen te Amsterdam, 1913, 16, page 628 ; 1914, 17, page 60 ; also G. K. Burgess and I. N. Kellberg, Journal of the Washington Academy of Science, 1916, 5, page 657.

thanks to Messrs. Thomas Bolton and Sons, Limited, Oakamoor, who gave and drew the metal, and more especially in this connection to Mr. M. A. Bolton; to Messrs. R. Wilson and E. Alkins, who were in charge of the drawing; to Mr. C. Bond, who has checked many of the results; to Professor Petavel, of the Engineering Department of the Victoria University of Manchester: and lastly to Professor C. A. Edwards, D.Sc., and the staff of the Metallurgical Department of the University of Manchester, for many valuable suggestions and criticisms.

THE RESISTANCE OF METALS TO PENETRATION UNDER IMPACT.*

(Including a Note on the Hardness of Solid Elements as a Periodic Function of their Atomic Weights.)

By Professor C. A. EDWARDS, D.Sc., Member of Council (Manchester University).

IN a recently-published paper† Mr. F. W. Willis and the present author described a very simple apparatus for making dynamic hardness determinations of metals. This instrument, which is illustrated in Fig. 1, was primarily designed for the purpose of making reliable hardness tests at elevated temperatures. In the paper just referred to extensive series of experimental results

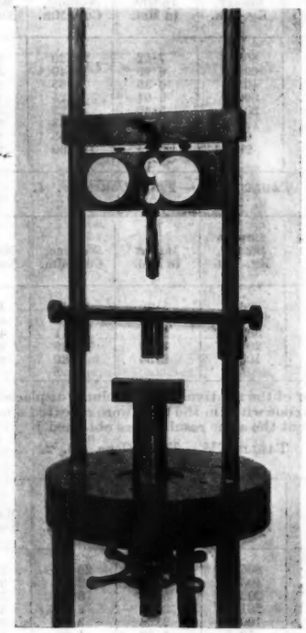


FIG. 1.

were recorded which were obtained by means of this new instrument. About twenty different samples were examined; these possessed widely different hardnesses —from 16 to 700—on the Brinell scale, and the data thus obtained were compared with the corresponding values obtained by the well-known methods devised by Brinell and Shore. The conclusions drawn from that investigation may be briefly summarised as follows:—

(1) When using a 10 mm. hardened steel ball rigidly fixed into a hammer, reliable hardness tests can be made by the dynamic method, and the dimensions of the indentation produced, under known impact, can be converted into terms of the Brinell scale. The equation expressing the relationship between these two values is $\frac{7455}{d^2} = H$, where d is the diameter of the indent, made with an impact of 63 in.-lb., and H is the Brinell hardness number.

(2) The results obtained appear to indicate that there is a law governing the resistance to penetration of metals which are capable of plastic deformation. This law, which applies to the very soft metals and to hardened tool steel, may be expressed by the equation $d = C \times E^{\cdot 25}$, where d is the diameter of indent made by a 10 mm. ball, C is a constant which varies with the hardness of the metal, and E is the energy of impact.

(3) Although from (2) it is clear that the value of C is a measure of the hardness of a given metal, it would not appear desirable to use it in its present form for expressing the relative hardnesses of different samples. It would be better to calculate by means of the above equation the impact energy required to produce an indent of a standard size. In this way a new hardness scale would be obtained, in energy units, which should be perfectly regular throughout its length.

(4) By using the impact method the time factor is almost if not entirely eliminated, and by means of the equation already mentioned correction can be made for the influence of varying degrees of deformation.

(5) The method of estimating the hardness of metals by the height of rebound of a small hammer after falling from a fixed height does not appear to be reliable. For this method to be satisfactory the energy of impact should be adjusted in such a way that the degree of deformation is the same for all comparative tests. Failing this, the indent should be measured and the observed rebound corrected to that which would occur if a standard indent were produced. Further, the impact should be sufficiently large to give a substantial indentation in order to minimise the influence of the character of the surface and the nature of the internal structure of the metal.

PRESENT INVESTIGATION.

The objects of the present investigation were:—

(*a*) To examine how the values for the factors C and n, in the equation $d = C \times E^n$, are affected by varying the diameter of the ball which is used as the striker.

(*b*) To determine the penetrating effects when cones of different angles are used.

(*c*) To make careful determinations of the hardnesses of pure metals in the completely annealed state, and where possible, similar observations with non-metallic elements, with the object of comparing the results thus obtained with some of the indisputable physical constants.

It may be noted here that in connection with question (*c*) it was originally intended to use the impact method for this purpose, but for various reasons, which will be stated later, this could not be done, and Brinell tests have almost entirely been relied upon.

Before proceeding to discuss the results contained in the present paper, the author wishes to draw attention to the following facts.

Since the present experiments were completed, and whilst the paper was being written, a short article by Professor Unwin has appeared,‡ in which he referred to an extensive piece of work by M. Martel.‖

Although this was the first reference to Martel's paper which the author had seen, it was quite evident from Professor Unwin's communication that he (Martel) had conducted a careful investigation on the impact method of making hardness tests. Through the kindness of Mr. G. C. Lloyd, secretary of the Iron and Steel Institute, the author has had an opportunity of reading Martel's original paper and examining the evidence upon which he bases his extremely interesting and important conclusions. The strikers used by Martel consisted of quadrangular pyramids having the dimensions given in Table I; the weights of the hammers corresponding with the four pyramids are also given in the same table.

TABLE I.

No.	Weight.	Length.	Width.	Depth.
	kg.	mm.	mm.	mm.
1	21·00	35·0	7·5	4·5
2	25·55	38·0	19·0	5·0
3	10·00	68·0	5·3	4·9
4	10·00	31·4	10·0	5·2

The height of fall varied from 100 mm. to 1,000 mm. Within the limits of his experiments Martel came to the following conclusions:—

(1) Other things being equal, the volume of the indent is proportional to the height of fall.

(2) The volume of the impression is proportional to the weight of the hammer.

(3) Other things being equal, the volume of the impression is independent of the shape of the striker.

(4) The ratio of the energy of impact to the volume of the impression is constant for any given metal and independent of the elements of the test. This constant, which gives the absolute resistance of the metal to superficial penetration, he suggested should be used as the hardness number. The number he used was the energy in kilogramme-millimetres necessary to displace 1 cub. mm. of the metal under test.

It will be observed that Martel's hardness number is an exceedingly simple one, and if it is found to apply to a wider range of shapes than he used it would have many advantages over the one suggested by Mr. Willis and the author, namely, to express the hardness as the energy required to produce an indent of a standard size. There is an obvious disadvantage in using pyramids such as Martel adopted, *i.e.*, the great difficulty there would be in getting a material that would keep the desired shape when making tests with moderately hard metals. This drawback does not present itself to anything like the same degree when hemispheres are used. For the present work, four spheres of different diameters and four cones of varying angles have been used. They were dimensioned as follows:—

No.	Diameter. Hemispheres.	No.	Cones. Base.	Height.	Angle.
	mm.		mm.	mm.	deg. 'min.
1	5	1	10	5	90 0
2	7	2	10	10	53 8
3	10	3	10	15	36 52
4	15	4	10	20	28 4

Lead.—The sample with which the experiments were made was sand-cast and hammered down from 1 in. thick to ½ in. thick.

Brinell Hardness.

Load.	Indent.	Hardness No.
500 kgm.	8.40 mm.	6.95

Scleroscope Hardness.

Soft hammer 2.0

Cone Tests.

Indentations were made under an impact of 17.5 in.-lb. with each of the four cones. The results are given in Table II, where it will be seen that the volume of metal displaced is practically the same for each striker. This means, of course, that Martel's number—based on the energy of impact in kilogramme-millimetres used in displacing 1 cub.-mm. of metal—is constant, namely, a little over 12. It may be noted that no difficulty was experienced in making the measurements of the indents with this metal; there was no raising of the material at the sides of the impression.

TABLE II.—*Lead. With Cones.*

——	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
Cone No. 1—				
17·5	201·6	5·02	16·55	12·18
Cone No. 2—				
17·5	201·6	3·96	16·25	12·40
Cone No. 3—				
17·5	201·6	3·46	16·27	12·39
Cone No. 4—				
17·5	201·6	3·12	15·90	12·68

Hemisphere Tests.—The results obtained with hemispheres are given in Tables III to V.

TABLE III.—*Lead. With Balls.*

——	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
5-mm. ball—				
7	80·6	4·30	9·91	8·21
7-mm. ball—				
35	403·2	6·66	50·66	7·94
7	80·6	4·86	9·50	8·48

TABLE IV.—*Lead. 10 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent Diameter in Mm.	Volume, Cub. Mm.	Martel's Number.
49·00	564·48	8·30	65·5	8·62
42·00	483·84	8·04	55·7	8·68
35·00	403·2	7·64	43·6	9·24
26·25	302·4	7·22	33·5	9·02
21·00	241·92	6·94	27·9	8·63
3·5	40·32	4·66	5·01	8·04
1·75	20·16	3·90	2·395	8·42

TABLE V.—*Lead. 15 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent Diameter in Mm.	Volume, Cub. Mm.	Martel's Number.
35·00	403·2	8·30	35·0	11·52
21·00	241·92	7·76	26·30	9·22
10·5	120·96	6·74	14·50	8·34
7·00	80·6	6·24	10·25	7·86
5·25	60·48	6·00	9·00	6·72
—	6·8	3·84	1·46	4·50

Only one test was made with the 5 mm. ball, two with the 7 mm., but a series with the 10 mm. and the 15 mm. balls. For the first three sizes there is excellent agreement between the Martel numbers, the differences being well within experimental error. In the case of the 15 mm. ball, however, there is a marked deviation in this respect. The Martel number for this striker shows a pronounced increase as the energy of impact was raised. It is, therefore, quite evident that in this instance the results are well outside the range wherein the $\frac{E}{V}$ is constant. It will be more convenient to discuss the varying values of C in the equation $d = C \sqrt[4]{E}$ at a later stage.

Aluminium.—This sample, which was of an exceptionally high degree of purity, was in the form of a ½-in. rolled plate in the completely annealed condition, and was kindly presented to the author by Dr. Gwyer.

Brinell Hardness.

Load in Kgm.	Indent.	Hardness No.
500	4.90 mm.	24.9
1,000	6.70 mm.	24.7

Scleroscope Hardness.

Soft hammer 5.0

Cone Tests.—The indents made in these tests were quite satisfactory in so much as there was little or no indication of the metal having been raised at the sides of the indents. The results are recorded in Tables VI to IX and plotted in Fig. 2 on the next page.

With cones Nos. 1 and 2, for which both high and low energies of impact were used, the respective values for $\frac{E}{V}$

* Paper read before the Institute of Metals, Tuesday, September 10, 1918.

† Proceedings of the Institution of Mechanical Engineers, June, 1918, pages 335–369.

‡ ENGINEERING, May 17, 1918, page 535.

‖ Colonel Martel, *Commission des Methodes d'Essai des Matériaux de Construction*, tome iii, Section A ("Métaux"), 1895, pages 261–277.

are sufficiently close to be regarded as constant when E was above, say, 17.5 in.-lb. For lower impacts, however, there appears to be a fall in the hardness number.

TABLE VI.—*Completely Annealed Aluminium. Cone No. 1. Angle, 90°.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
105·00	1209·6	6·40	34·10	35·45
70·00	806·4	5·60	—	—
52·5	604·8	5·26	19·06	31·7
35·00	403·2	4·52	12·09	33·35
26·25	302·4	4·14	9·27	32·6
24·5	282·2	4·06	8·89	31·7
21·00	241·9	3·82	7·30	33·14
17·5	201·6	3·62	6·21	32·46
10·5	120·96	3·14	4·04	29·9
8·75	100·8	3·10	3·89	25·9

TABLE VII.—*Completely Annealed Aluminium. Cone No. 2. Angle, 53° 8′.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
105·00	1209·6	4·88	29·68	40·75
70·00	806·4	4·30	20·71	38·93
52·5	604·8	4·00	16·76	36·08
35·00	403·2	3·50	11·10	36·32
31·5	352·9	3·40	10·29	34·30
26·25	302·4	3·06	7·64	39·58
17·5	201·6	2·76	5·49	36·70
14·00	161·3	2·64	4·81	33·53
8·75	100·8	2·22	2·85	35·35
7·00	80·6	2·08	2·35	34·46
3·5	40·3	1·70	1·28	31·49
1·75	20·15	1·32	0·60	33·59

TABLE VIII.—*Completely Annealed Aluminium. Cone No. 3. Angle, 36° 52′.*

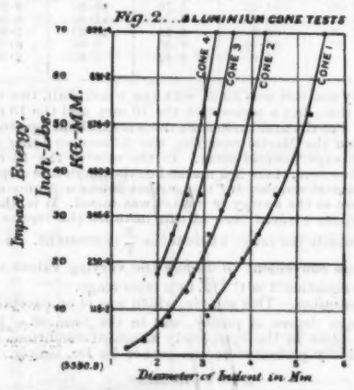
Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
105·00	1209·6	4·20	29·08	41·59
70·00	806·4	3·60	18·32	44·01
52·5	604·8	3·24	13·33	45·30
35·00	403·2	2·90	9·56	41·20
17·5	201·6	2·30	4·77	42·47

TABLE IX.—*Completely Annealed Aluminium. Cone No. 4. Angle, 28° 4′.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
105·00	1209·6	3·90	31·03	38·98
70·00	806·4	3·24	17·78	45·35
52·5	604·8	2·96	13·57	44·57
35·00	403·2	2·60	9·20	43·82
26·25	302·4	2·30	6·36	47·50
17·5	201·6	2·00	4·19	48·10

With one exception, the results obtained for cones 3 and 4 show that $\frac{E}{V}$ is practically constant for each respective series. When comparing the Martel numbers

Fig. 2. ALUMINIUM CONE TESTS



for the different cones it will be noted that these tend to become greater as the angle of the cone diminishes.

Hemisphere Tests.—The experimental data as given in Tables X to XIII, and plotted in Fig. 3.

With this form of striker the experimental observations are much more regular than in the case of the cones. Broadly speaking, the Martel numbers for each series of tests, which cover a wide range of impacts, are in very close agreement. The change in this number as the diameter of the ball increases is rather small, but it is quite noticeable, and in view of the large number of tests this can scarcely be regarded as due to experimental error.

Tin.—This sample was prepared by first casting the metal in a 1-in. sand mould. It was then hammered down to a ¼-in. plate and annealed at 110 deg. C. for three hours.

Brinell Hardness.

Load in Kgm.	Indent.	Hardness No.
500	6.06 mm.	15.6

Scleroscope Hardness.

Hard hammer	6.0
Soft hammer	7.5

Cone Tests.—It is necessary to state that in these experiments the results, which are given in Tables XIV

Fig. 3. ALUMINIUM BALL TESTS

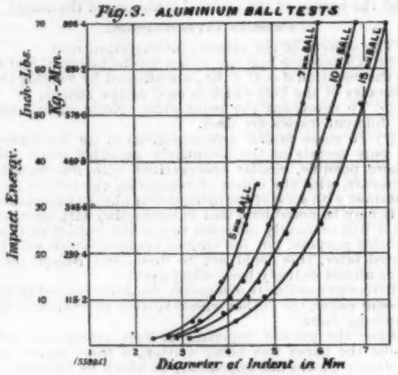
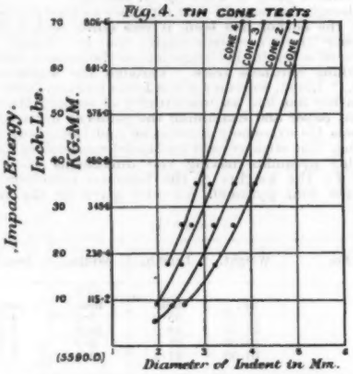


Fig. 4. TIN CONE TESTS



to XVII and plotted in Fig. 4, must be examined with some caution, because they do not exactly represent the

TABLE X.—*Aluminium completely Annealed. 5 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
35·00	403·2	4·70	16·8	24·0
31·5	352·9	4·50	12·65	27·9
28·0	322·56	4·44	12·1	26·6
26·25	302·4	4·42	11·6	26·0
17·5	201·6	4·08	7·4	25·6
14·00	161·28	3·84	5·3	30·4
10·5	120·96	3·68	4·42	27·3
5·25	60·48	3·24	2·68	22·6
1·75	20·16	2·34	—	—

TABLE XI.—*Aluminium completely Annealed. 7 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·00	806·4	6·02	27·05	29·7
52·5	604·8	5·68	19·95	30·3
35·00	403·2	5·18	12·95	31·1
26·25	302·4	4·90	10·0	30·2
17·5	201·6	4·50	6·80	29·6
14·00	161·28	4·32	5·85	27·6
10·5	120·96	4·04	4·30	28·1
5·25	60·48	3·40	2·05	29·5
1·75	20·16	2·70	0·795	25·3

true amount of metal which was displaced. This defect arises from the fact that there was a decided tendency for the metal to be squeezed to the sides of the indentation and not to be pressed inwards, as was evidently the case for lead and aluminium. This objectionable feature applies more particularly to cones Nos. 2, 3 and 4; in the case of No. 1, the impression was practically the same as for those previously considered. Since the diameters of the indents were measured, it follows that the calculated volume of the material displaced was greater than if the depth of the impression had been measured, and as a result it naturally leads to a low Martel number.

TABLE XII.—*Aluminium completely Annealed. 10 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·00	806·4	6·85	26·3	30·66
63·00	725·76	6·66	22·5	32·25
56·00	645·12	6·44	20·0	32·2
49·00	564·5	6·24	17·4	32·44
42·00	483·8	6·00	14·7	32·90
35·00	403·2	5·74	12·1	33·32
29·75	342·7	5·44	9·7	35·33
24·5	282·2	5·28	8·5	33·20
17·5	201·6	4·84	5·85	34·46
14·00	161·28	4·68	5·10	31·42
10·5	120·96	4·46	4·17	29·00
8·75	100·8	4·20	3·27	30·82
7·00	80·64	3·90	2·395	33·66
5·25	60·48	3·66	1·85	32·60
3·5	40·32	3·32	1·23	32·78
1·75	20·16	2·88	0·68	29·65

TABLE XIII.—*Aluminium completely Annealed. 15 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·00	806·4	7·52	23·20	34·7
52·5	604·8	6·95	16·40	36·8
35·00	403·2	6·36	11·65	34·6
26·25	302·4	6·04	9·25	32·7
17·5	201·6	5·49	6·25	32·3
10·5	120·96	4·82	3·68	32·9
5·25	60·48	4·18	2·05	29·5
1·75	20·16	3·14	166·00	30·5

TABLE XIV.—*Tin. Cone No. 1. Angle, 90° 0′.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·00	806·4	5·20	18·40	43·8
35·00	403·2	4·06	8·75	46·0
26·25	302·4	3·60	6·11	49·4
17·5	201·6	3·20	4·29	47·0
8·75	100·8	2·56	2·20	45·8

[In view of the relatively small volume displaced when using this cone with tin the tests were repeated a number of times, but the same results were obtained.]

TABLE XV.—*Tin. Cone No. 2. Angle, 53° 8′.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·00	806·4	4·82	29·3	27·5
35·00	403·2	3·62	12·42	32·4
26·25	302·4	3·20	8·57	35·2
17·5	201·4	2·88	6·25	32·2
8·75	100·7	2·28	3·10	32·5
5·25	59·5	1·92	1·85	32·1

TABLE XVI.—*Tin. Cone No. 3. Angle, 36° 52′.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·00	806·4	4·30	31·08	25·9
35·00	403·2	3·14	12·16	33·1
26·25	302·4	2·70	8·58	35·2
17·5	201·6	2·50	6·12	32·9
8·75	100·7	2·0	3·14	32·07

TABLE XVII.—*Tin. Cone No. 4. Angle, 28° 4′.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·00	806·4	3·84	29·64	27·2
35·00	403·2	2·84	11·99	33·6
26·25	302·4	2·52	8·17	37·0
17·5	201·6	2·24	5·86	34·4

As regards cones 2, 3 and 4, it will be noted that in each series the highest impact gives the lowest Martel number, and that as the energy of impact is raised this number first increases and then decreases. With the possible exception of the values recorded for impacts of 70-in. lb. the above-mentioned variations are quite small and may be attributed to errors of measurement. The low hardness numbers obtained for the highest impacts may be due to the excessive piling up of the metal at the sides of the indent, giving an abnormally high figure for displaced metal.

It is interesting to note that the maximum difference between the values obtained with cones 2, 3 and 4 for any given impact is only 2. From this it seems reasonable to conclude that with any given impact all cones between the angles 53° 8′ and 28° 4′ will give a constant figure for $\frac{E}{V}$, but the evidence is not complete enough to

form a more general conclusion. As regards cone No. 1, the energy required to displace unit volume of metal is greater than for the three cones of smaller angle. The hardness number for this cone is from 12 to 16 higher than those for the others. A certain amount of this difference is undoubtedly due to the metal not being raised at the sides of the indent in this series of tests, but in the absence of more reliable data it is impossible to say whether it is entirely accounted for in this way.

Hemisphere Tests.—The results for the four series of tests are given on Tables XVIII to XXI, and these are plotted in Fig. 5. In view of the unsatisfactory character

TABLE XVIII.—*Tin. 5 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
35·0	403·2	4·50	12·65	31·8
24·5	282·2	4·16	8·22	34·3
21·00	241·9	4·10	7·60	31·8
17·5	201·6	4·00	6·60	32·1
14·00	161·28	3·82	5·15	31·5
10·5	120·96	3·52	3·72	32·5
7·00	80·64	3·26	2·75	29·3
5·25	60·48	3·02	2·05	29·5
3·50	40·32	2·72	1·25	32·2
				Average: 31·66

TABLE XIX.—*Tin. 7 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
35·00	403·2	5·12	12·2	33·0
26·25	302·4	4·70	8·25	36·7
21·00	241·9	4·48	6·70	36·1
17·5	201·4	4·24	5·85	34·4
10·5	120·96	3·76	3·14	38·5
7·0	80·64	3·54	2·44	33·0
5·25	60·48	3·30	1·80	33·6
3·5	40·32	2·96	1·14	35·4
				Average: 35·21

TABLE XX.—*Tin. 10 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent Diameter in Mm.	Volume, Cub. Mm.	Martels' Number.
70·00	806·4	6·4	19·42	41·52
56·5	605·9	6·16	16·46	36·81
42·00	482·8	5·78	12·40	38·80
35·00	403·2	5·54	10·39	38·81
28·00	322·56	5·30	8·62	37·46
18·00	207·36	4·80	5·67	36·56
14·00	161·28	4·50	4·34	39·44
7·00	80·64	3·80	2·155	37·16
3·5	40·32	3·30	1·21	37·42
1·75	20·16	2·66	0·503	40·30
				Average: 38·43

TABLE XXI.—*Tin. 15 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent Diameter in Mm.	Volume, Cub. Mm.	Martel's Number.
35·00	403·2	6·10	9·60	42·00
26·25	302·4	5·70	7·30	41·4
17·5	201·6	5·10	4·67	43·1
12·25	141·1	4·80	3·60	39·2
8·75	100·8	4·36	2·45	41·1
5·25	60·48	3·94	1·62	37·3
3·5	40·32	3·60	1·12	36·0
1·75	20·16	3·02	0·60	33·6
				Average: 39·21

of the indents obtained with this metal when cones were used, it is perhaps important to record that the indents made with the hemispheres were quite normal.

The first item to note is that the hardness number, or $\frac{E}{V}$, obtained for each particular hemisphere under widely different conditions as regards the value for E, are in very good agreement with each other. In fact, with one exception (1.75 in.-lb. for the 15 mm. ball) the greatest difference between the maximum and minimum figures is 6.0. In comparing $\frac{E}{V}$ for each of the four series of tests it will be observed that there is a decided indication that the number becomes greater as the diameter of the ball increases. The averages are :—

Diameter of ball ...	$\frac{E}{V}$
5 mm. ...	... 31.66
7 mm. ...	... 35.52
10 mm. ...	... 38.43
15 mm. ...	... 40.00 excluding the observation for 1.75 in.-lb.

COPPER-ZINC PLATE (28 PER CENT ZINC).

Brinell Hardness.

Load in Kg.	Indent.	Hardness No.
3,000	4.52	177

Soleroscope Hardness.

Hard hammer	33.5

Cone Tests.—Attempts were made to carry out experiments with this metal when using cones as strikers, but they had to be abandoned on account of the excessive raising of the metal around the indent. The trials which have been made in this direction appear to indicate that with the cones used by the author the raising of the metal at the sides of the impression increase with the hardness of the metal.

Fig. 5. TIN BALL TESTS

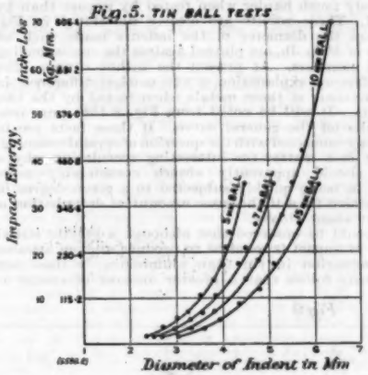


Fig. 6. COPPER ZINC-PLATE

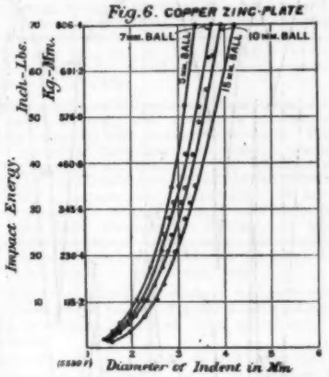


Fig. 7. CONSTANTS

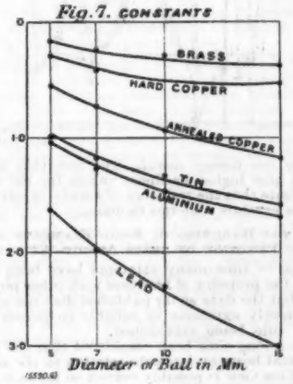
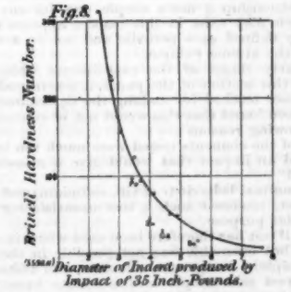


Fig. 8.



Hemisphere Tests.—The data for these experiments are recorded in Tables XXII to XXV and plotted in Fig. 6. As regards the values for $\frac{E}{V}$ in each series of tests, it will be noticed that whilst there is a certain amount of irregularity which may be due to experimental error, the evidence indicates that there is a more or less progressive increase in this figure as the impact is lowered. Further, when comparing these numbers for the different hemispheres it will be observed that there is quite a pronounced increase as the diameter of the ball is raised.

General Discussion.—The experiments which have been made with cones of different angles are not sufficiently accurate or extensive to permit of any definite conclusions being drawn. The data obtained has been rendered somewhat unreliable, largely owing to the author not being in a position to measure the depths of the impressions instead of the diameters. This difficulty has been intensified by the use of small angled cones, which cause the sides of the indents to become very considerably higher than the original surface of the specimen. These

TABLE XXII.—*Copper-Zinc Plate. 5 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
140·00	1612·8	4·00	6·82	236·4
105·00	1209·6	3·76	5·06	235·1
70·00	806·4	3·40	3·20	252·0
52·5	604·8	3·16	2·35	253·1
35·00	403·2	2·86	1·50	268·8
17·5	201·6	2·40	0·710	283·9
10·5	121·0	2·10	0·407	297·3

TABLE XXIII.—*Copper-Zinc Plate. 7 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·00	806·4	3·74	3·08	261·5
63·00	745·8	3·66	2·80	259·0
52·5	604·8	3·44	2·16	280·0
42·00	483·8	3·16	1·52	318·0
35·00	403·2	3·02	1·25	322·5
31·5	352·9	2·92	1·08	326·7
28·00	322·56	2·82	0·94	343·0
24·5	282·25	2·72	0·805	350·5
21·00	241·9	2·66	0·74	321·9
10·5	121·00	2·25	0·38	318·0
7·0	80·6	1·98	0·22	366·0

TABLE XXIV.—*Copper-Zinc Plate. 10 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
70·0	806·4	3·94	2·50	322·5
63·0	725·8	3·75	2·05	354·0
56·0	645·1	3·66	1·85	348·7
49·0	546·5	3·48	1·53	368·9
42·0	483·8	3·32	1·32	366·3
35·0	403·2	3·16	1·012	396·4
31·5	362·4	3·10	0·936	387·1
24·5	282·25	2·89	0·710	397·5
21·0	241·9	2·83	0·652	371·0
17·5	201·6	2·69	0·532	378·9
14·0	161·3	2·46	0·390	413·5
10·5	121·0	2·31	0·287	421·6
7·0	80·6	2·06	0·180	447·7
5·25	60·5	1·94	0·141	429·0
3·5	40·3	1·71	0·084	479·7
1·75	20·15	1·46	0·044	458·0

TABLE XXV.—*Copper-Zinc Plate. 15 Mm. Ball.*

Impact Energy in.-lb.	Impact Energy, Kg.-Mm.	Indent in Mm.	Volume, Cub. Mm.	Martel's Number.
140·0	1612·8	4·94	4·12	391·4
105·0	1209·6	4·54	2·88	420·0
70·0	806·4	4·22	2·20	366·7
35·0	403·2	3·40	0·92	438·2
31·5	352·9	3·24	0·75	470·0
28·0	322·56	3·14	0·68	472·9
24·5	282·25	3·02	0·57	495·0
21·0	241·9	2·96	0·52	465·4
14·0	161·3	2·70	0·35	460·8
10·5	121·0	2·54	0·29	417·0

remarks do not apply to the tests made with lead, nor to cone No. 1, having an angle of 90 for either aluminium or tin.

As regards lead, the energy required to displace unit volume of metal was the same for each cone, which fits in with Martel's law. So far as the present experiments are concerned, this cannot be said to apply to aluminium and tin, but it is quite possible that the observed differences in this connection may be due to the manner in which the measurements were made. The results obtained for lead with the four cones, and the 5 mm., 7 mm. and 10 mm. hemispheres, show that $\frac{E}{V}$ is constant for each type of striker; but there is a substantial difference in this respect when the values for the two types are compared with one another. In a lesser degree this difference between the ratio $\frac{E}{V}$, for the two kinds of strikers, is manifest in the case of aluminium and tin. This ratio is therefore not entirely independent of the shape of the striker.

It is somewhat remarkable that whilst $\frac{E}{V}$ is constant for the 5 mm., 7 mm. and 10 mm. hemispheres, it varies very considerably with varying impacts with the 15 mm. hemisphere. This peculiar feature is not revealed when testing harder metals.

The tests made with aluminium indicate that $\frac{E}{V}$ is practically constant for any particular hemisphere, but

there is a slight though systematic increase in this ratio as the diameter of the hemisphere is increased. The same applies to tin, but in this case the change is more pronounced.

As regards the copper-zinc alloy, the ratio $\frac{E}{V}$ becomes progressively greater as the energy of impact decreases, and it also becomes greater with an increase in the diameter of the hemisphere.

Discussion of the Equation $C = \frac{d}{\sqrt[4]{E}}$.—It would take up an unnecessary amount of space to record all the figures which have been calculated from each indent, and to give a detailed description of the manner in which they vary would take more time than the author has at present at his disposal. In view of this, and the fact that it is felt that still more careful and extended observations are needed before any very decided conclusions can be safely made, it is proposed to give only a brief account of the general bearing of the results in this connection. The need for further work will be evident when it is remembered that a comparatively small difference in the size of an indent has rather a serious effect upon the value of the factor C. Before it can be stated whether the above equation is substantially correct for all metals when using hemispheres of different diameters, it will be necessary to have a much more delicate means of measuring the indents than has been possible in the course of the present investigation. An error of plus or minus 0.05 of a mm. in many of the low indentations is sufficient to have an appreciable effect upon the value of C.

Generally speaking, it may be concluded that the experiments with the different hemispheres indicate that the diameter of the indents agree very closely with the equation $d = C \sqrt[4]{E}$. Most of the observed deviations are well within the range of possible error due to defective measurements. With impacts between, say, 20 in.-lb. and 70 in.-lb. the values for C may be regarded as virtually constant. Even within this range of impact there is, however, a slight tendency for C to become greater as the impact decreases, and with still lower impacts this change tends to increase. This applies more especially to the softer metals, for as the hardness increases there is certainly less deviation from the above general equation. In fact, in the few cases with hard samples, where the indents have been measured under the microscope, the equation as it stands is in perfect agreement with the experimental data. In spite of this, however, the author is at present inclined to the view that the above expression is not absolutely accurate, but that an additional correction will be required before it truly represents the resistance to penetration under impact.

In order to illustrate the variation of the factor C with the different hemispheres, these have been plotted for six samples in Fig. 8. These curves are obviously very similar, and if the necessary correction can be satisfactorily introduced in the equation $d = C \sqrt[4]{E}$, it may be possible by means of curves of this kind to get an expression which will embrace changes in the diameter of the hemisphere.

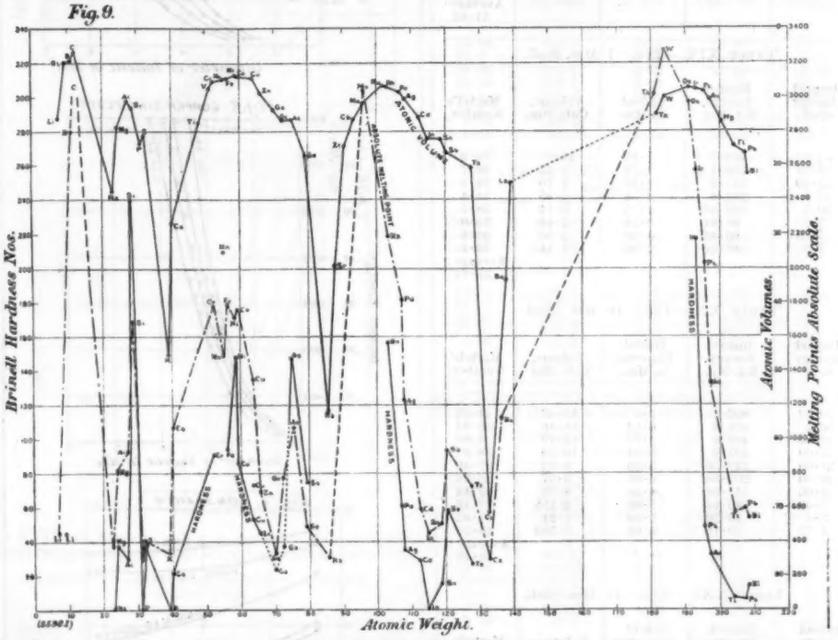
Static and Dynamic Hardness.—On referring back to the data of aluminium and tin, it will be found that the Brinell hardness number for the former is 24.8, and that of the latter is 15.6; or, in other words, tin is 37 per cent. softer than aluminium. Having first obtained these results, it was rather bewildering to find that a greater impact energy was required to produce a given sized indent in tin than in aluminium. Since up to the time this fact was observed it had been found that there was apparently a definite relationship between the impact indents and the Brinell hardness, it was quite natural that the results for aluminium and tin, where the order of their hardnesses was completely reversed when tested by the two methods, were regarded with considerable doubt, and it was not until they had been repeated a number of times that the author felt justified in accepting them. Having once established the fact, it became a matter of interest to inquire why there should be such a marked difference in the behaviour of one of these metals when tested by impact, and also to examine the data which was at hand, with a view of seeing whether any of the other metals behaved in a similar manner.

After plotting the diameters of the indents produced under a fixed energy of impact, for a number of samples, against their corresponding Brinell numbers, it was found that the point for tin was well off the general curve. Thus it was evident that the reversal in the order of the hardness by the two methods was due to tin showing an abnormally high hardness under impact and not to aluminium appearing softer by this test. Knowing that tin is one of the metals which gives rise to the formation of twin crystals when subjected to certain kinds of mechanical deformation, it was thought that the peculiar feature observed above was in some way connected with this property. Whether this is so or not the author is unable to say, but the following simple experiment seems to indicate that tin undergoes a different kind of deformation when subjected to quick, than to slow, applications of stress. Small specimens were prepared by casting on polished steel; some of these were slowly deformed by pressing the point of a pin into the surface, whilst others were quickly stressed by hitting the head of the pin whilst the point rested on the surface. The indentations were then examined under the microscope, and in all cases the indent which was formed quickly was found to be surrounded by large numbers of twin crystals, whereas with very slow and steady pressures there were practically no twin crystals produced, deformation evidently proceeding by a process of ordinary slip. In some instances twin crystals were entirely absent with the slow pressures, but to get this result great care is required, as relatively insignificant side thrusts cause the twinning to appear.

In view of the behaviour of tin the results which had already been obtained with the Brinell and impact tests for cadmium and zinc, which are known to give twin crystals by mechanical strain, were examined. Strange to say these metals showed the same characteristics as tin, namely, in comparison with other metals they were relatively much harder when tested by impact than by Brinell. These results are clearly illustrated in Fig. 8, where the diameter of the indents made with an impact of 35 in.-lb. are plotted against the corresponding Brinell numbers. At present the author cannot offer a satisfactory explanation of the marked difference in the behaviour of these metals when tested by the two methods. It will be noted from Fig. 8 that pure iron also falls off the general curve. If these facts are in some way connected with the question of crystal twinning, then it is a matter for interesting speculation why a metal should apparently absorb considerably more energy in being quickly subjected to a given degree of deformation than if the same amount of deformation is brought about slowly.

It should be observed that although a greater initial energy of impact is required to produce a given amount of deformation in tin than aluminium, it does not necessarily follow that a greater amount of energy is absorbed by the former metal. The fact that scleroscopic tests give higher hardness values for tin would seem to indicate that the resilience of a metal is relatively higher if its crystals undergo twinning.

Fig. 9.



NOTE ON THE HARDNESS OF SOLID ELEMENTS AS A PERIODIC FUNCTION OF THEIR ATOMIC WEIGHTS.

From time to time many attempts have been made to correlate the property of hardness with other physical properties, but the data so far published does not appear to be sufficiently extensive or reliable to permit of a satisfactory rule being established.

It has for a long time been considered that the hardness of a metal bears an intimate relation to its atomic volume.* This view is possibly correct so far as it goes, but the evidence which the author has obtained indicates that the relationship is not a simple one, for any connection which may exist in this respect appears to be more clearly defined as a periodic and not as a direct function of the atomic volume.

In the early stages of the experiments which are recorded in this section of the paper, it was intended to use the impact method for making the determinations, but it was soon found that this would not be convenient, for the following reasons:—

1. Many of the elements tested were much too brittle to withstand an impact that would give a measurable indent; and

2. The abnormal behaviour of tin, cadmium, and zinc, under impact, rendered such a test unsatisfactory for this particular purpose.

The Brinell test has therefore been used where it could be applied, but even this was not possible in the case of silicon, sulphur, manganese, selenium, and tellurium. In those cases scleroscopic measurements have been made, and the corresponding Brinell values estimated from a diagram which was published in the earlier paper by Mr. Willis and the author. All the malleable metals were in the rolled but completely annealed condition. Cast samples were used for the brittle elements.

The manganese sample was of very doubtful purity, and this, coupled with the fact that an estimated Brinell determination from a scleroscopic reading is untrustworthy, marks the recorded value for this element as an unreliable one. The purity of the magnesium sample was also only a little over 99 per cent., and on that account the hardness will no doubt be on the high side.

All the remaining samples were of the highest possible commercial purity, and the hardness numbers given may therefore be taken as being substantially correct.

The results are given in Table XXVI and plotted against atomic weights in Fig. 9. A mere glance at this diagram is quite sufficient to show that the hardness of solid elements is a periodic function of their atomic weights. When these curves are compared with the periodic changes of the atomic volumes of the elements, also plotted in Fig. 9, it will be seen that there is a decided connection between the two. There is, however, an even closer parallelism between the curves for absolute melting points and hardness, than for hardness and atomic volume. Practically all the changes in the melting-point curve are reflected by corresponding changes in hardness.

Owing to the pressure of other work, the author regrets that he cannot discuss the bearing of these results on the work and theories of Traube, Richards, Van der Waal, Benedicks, and the recent interesting publications in this Journal by Dr. S. W. Smith. It is felt that the facts are of sufficient importance to stand alone, and may be of more use to other investigators if they are not accompanied by hurried theoretical deductions. In the near future the author hopes to have a convenient opportunity of dealing with some of the theoretical problems relating to these facts.

TABLE XXVI.

Element.	Source.	Load in Kg.	Indent.	Hardness Number.
Sodium ..	Chem. Museum..	3·20	7·10	0·07
Magnesium	Met. Lab. ..	2,000	7·92	38·3
Aluminium	Dr. Gwyer ..	1,000	6·70	24·7
Silicon ..	Chem. Museum..	—	Estimated	240·0
Phosphorus	Chem. Museum..	12·5	6·90	0·63
Sulphur ..	Chem. Lab. ..	—	Estimated	36·0
Potassium	Chem. Lab. ..	1·6	7·30	0·037
Calcium ..	Chem. Lab. ..	1,000	7·02	22·2
Chromium	Chem. Museum..	500	2·02	91·0
Manganese	Chem. Museum..	—	Estimated	210·0 (?)
Iron ..	Met. Lab. ..	3,000	5·96	97·0
Nickel ..	Mr. Boeddicker	3,000	4·98	144·0
Cobalt ..	Chem. Museum..	1,000	5·85	86·0
Copper ..	Mr. Alkins ..	1,000	4·72	53·0
Zinc ..	Met. Lab. ..	3,000	8·15	45·5
Arsenic ..	Chem. Lab. ..	1,000	2·92	147·0
Selenium ..	Chem. Museum..	—	Estimated	75·0
Rhodium ..	Johnson, Matthey	3,000	4·80	156·0
Palladium	Johnson, Matthey	1,000	4·44	61·0
Silver ..	Johnson, Matthey	1,000	5·68	37·0
Cadmium ..	Met. Lab. ..	1,000	6·26	29·0
Indium ..	Chem. Museum..	12·5	4·12	1·0
Tin ..	Met. Lab. ..	500	6·06	15·6
Antimony..	Met. Lab. ..	2,000	6·24	58·0
Tellurium	Chem. Museum..	—	Estimated	27·0
Iridium ..	Johnson, Matthey	3,000	4·10	217·0
Platinum ..	Johnson, Matthey	1,500	6·20	44·3
Gold ..	Johnson, Matthey	1,000	5·90	33·0
Thallium ..	Chem. Museum..	250	6·22	7·3
Lead ..	Met. Lab. ..	500	8·40	6·95
Bismuth ..	Chem. Museum..	5,000	7·20	14·0

The author wishes to express his keen appreciation to Dr. Gwyer, Mr. Boeddicker, and Mr. Alkins for the samples they have presented, and especially to Messrs. Johnson, Matthey and Co., for their very substantial assistance in so readily lending the author large samples of such valuable metals as silver, gold, platinum,

* S. Bottone, *Chemical News*, 1873, 27, 215.

palladium, rhodium, and iridium, and for the keen interest they have taken in the general progress of the work.

The author gratefully acknowledges the valuable assistance given by Mr. F. Buckingham, B.Sc., of the Engineering Department, in making many of the necessary calculations.

NOTES FROM THE NORTH.

GLASGOW, Wednesday.

Scotch Steel Trade.—All things considered, the work of steel production in the West of Scotland runs very smoothly, the output is maintained at an exceptionally high level and little change in the existing conditions falls to be noted. An increase in the available supply of scrap steel and pig-iron has helped to relieve the anxiety of those engaged in the task of endeavouring to bring about a supply more in accordance with the needs of the consumers whose war-work activities are of vital importance to the nation. It has meant also that the wants of the Allies can be better met, a fact of no small moment viewed from the standpoint of current events on the Western front. If things go on as satisfactorily as at the moment a surplus of finished steel ought to result shortly, the worst of the pressure having been greatly relieved. The Clyde shipbuilders continue to absorb enormous quantities of steel, a circumstance which is not likely to show any slacking-off for some considerable time.

Malleable Iron Trade.—The malleable iron trade forges ahead, makers striving by all means at their command to keep the supply level with the demand, not an easy matter considering the clamant nature of so many of the demands. Government control has done much to straighten out affairs, and the speeding-up of output has been exceptional. Coal and labour troubles are just as serious as in kindred industries, being at the moment the only drawback to that greatly increased output so ardently longed for. Many Government contracts are on hand, the pressure for delivery is intense, and in consequence of the urgent character of this work very little of any other description can be accepted meantime.

Scotch Pig-Iron Trade.—Pig-iron of every brand is in constant request. Work of national importance naturally comes first; and as every ton of hematite produced is specially required in this respect none is available for other purposes. It is much the same with foundry iron, and consequently these two brands in particular are practically off the market so far as general business is concerned. In order to conserve the output for the most important of all uses in the meantime, little or nothing is available for export, the scheme of distribution taking the claims in priority of urgency. This has worked well, otherwise it would have been chaos. Prices continue firm.

Inverness Builds a Steel Vessel.—There has just been launched from the slipway of the Rose Street Foundry and Engineering Company, Thornbush, Inverness, the first steel vessel built in the northern capital. At the launching ceremony, which was performed by his wife, Mr. T. B. Morison, K.C., M.P., Solicitor-General for Scotland, made interesting reference to the great possibilities of Inverness in connection with industrial development, noting particularly the water power at command in and around the town, as well as in many other parts of the Highlands. The Board of Trade and the Ministry of Reconstruction, he said, were thoroughly aware of the numerous untapped sources of supply, many of which, no doubt, would be put to good use as soon as possible after the termination of the war.

NOTES FROM SOUTH YORKSHIRE.

SHEFFIELD, Wednesday.

Hull Coal Trade.—Compared with the corresponding period of last year, the quantity of coal (232,556 tons) sent to the port of Hull during the month of August, showed a decrease of 14,906 tons. At the top of the list are the figures for Denaby and Cadeby Main, 15,906 tons, against 27,284 tons in August, 1917. The aggregate tonnage received at the port since January this year was 1,800,471 tons, a decrease of 135,911 tons compared with the corresponding period of 1917.

Iron and Steel.—The demand for certain classes of war material is keeping the departments concerned exceedingly busy. Generally speaking, however, little that is new characterises the trade outlook. Crucible steel makers are still comparatively free from pressure, and it would take a big crop of new business calls fully to employ the entire resources of the trade. Conditions just the reverse obtain at the open-hearth steel furnaces, where a considerable output is being easily disposed of. Even though the general conditions are comparatively slack, difficulty is experienced in obtaining the requisite amount of labour, the withdrawal on a large scale of highly skilled youths for military duties having made it a problem in many works to keep operations going. Big calls are being made on local industry for the supply of engineering tools, saws and similar articles, the demands for these from the military authorities in themselves representing a considerable amount of trade. In the cutlery industry the principal orders in hand are for table knives, razors, scissors and pocket knives. An order for 100,000 safety razor blades for the European Army has just been placed in Sheffield.

South Yorkshire Coal Trade.—Supply continues to be unequal to the demand by a considerable margin. All classes of home consumers are pressing for supplies of best steams, but orders can only be considered after heavy export requirements have been met. There are keen requests for cobbles, nuts and slacks, but output is going away day by day on contract orders. In the household section there is a general outcry for supplies, but here again there is nothing for open market. Cokes are scarce with prices at the maximum. Quotations:—Best branch handpicked, 27*s.* to 28*s.*; Barnsley best Silkstone, 27*s.* to 27*s.* 6*d.*; Derbyshire best brights, 25*s.* to 26*s.*; Derbyshire house coal, 22*s.* 6*d.* to 23*s.* 6*d.*; best large nuts, 22*s.* 6*d.* to 23*s.* 6*d.*; small nuts, 21*s.* 6*d.* to 22*s.* 6*d.*; Yorkshire hards, 22*s.* 6*d.* to 23*s.* 6*d.*; Derbyshire hards, 21*s.* 9*d.* to 22*s.* 9*d.*; best slacks, 18*s.* to 19*s.* 6*d.*; seconds, 16*s.* to 18*s.*; smalls, 13*s.* to 14*s.*

NOTES FROM CLEVELAND AND THE NORTHERN COUNTIES.

MIDDLESBROUGH, Wednesday.

The Cleveland Iron Trade.—Interest at present centres in anticipated further advance in export quotations of Cleveland pig-iron. Though no official announcement has yet been made it is believed that the advance will be 5*s.*, and that it will be retrospective as from July 1. Business in Cleveland pig-iron is fairly active, but an obstacle to trade is the short supply of foundry iron, and especially No. 3 quality, for home use, due to larger shipments to the Allies. This month's allocations are somewhat smaller, but sufficient of the iron allotted is not obtainable to enable merchants to fulfil their obligations. If shipments of iron cannot be made, more foundry pig-iron will be available for home use before the end of the month. It is gratifying, however, to learn that, so far, the shortage cannot be described as acute. Forge iron is quite plentiful, and is being rather pressed on the market for both early and forward delivery, and makers' stocks of this quality are understood to be accumulating. For home consumption, No. 3 Cleveland pig-iron, No. 4 foundry and No. 4 forge are all quoted 95*s.*, and No. 1 is 99*s.*; and for shipment to France and Italy, No. 3 and the lower qualities are 119*s.*, and No. 1 is 124*s.*

Hematite Iron.—Demand for East Coast hematite is as heavy as ever, and producers experience some difficulty in coping with their commitments. Under the careful system of distribution, however, consumers are receiving supplies sufficient for their absolute requirements, and what iron can be spared for the Allies is being despatched as expeditiously as possible. So far as can be ascertained the protest of merchants at losing their trade with Italy through the Ministry of Munitions having taken charge of Italian needs has been without effect. Nos. 1, 2 and 3 are 122*s.* 6*d.* for home use, and 147*s.* 6*d.* for export to France and Italy.

Foreign Ore.—Fairly satisfactory accounts are given of the foreign ore trade. Suppliers are understood to be coming forward well, and most consumers are now well placed.

Coke.—The supply of coke is still short, and many expedients are resorted to so as to maintain regular deliveries to the blast furnaces. Average furnace quality is 33*s.* at the ovens, and low phosphorus sort 35*s.* 6*d.* at the ovens. From 65*s.* to 65*s.* 7*d.* f.o.b. is offered for foundry coke for neutrals.

Manufactured Iron and Steel.—Production of manufactured iron and steel is on an enormous scale, notwithstanding difficulty experienced in obtaining fuel supplies. There is a large home demand for constructional material, but needs of the shipyards are so adequately met that pressure for delivery is not heavy. Some increase of shipments of certain descriptions of finished iron and steel to France and Italy are reported. Prices, all round, are very stiff. The following are among the principal market quotations:—Common iron bars, 14*l.* 15*s.*; best bars, 15*l.* 15*s.*; double best bars, 16*l.* 15*s.*; triple best bars, 17*l.* 15*s.*; iron ship plates, 15*l.* 10*s.*; iron ship angles, 13*l.* 17*s.* 6*d.*; iron ship rivets, 21*l.*; steel ship plates, 11*l.* 10*s.*; steel ship angles, 11*l.* 2*s.* 6*d.*; steel boiler plates, 12*l.* 10*s.*; steel strip, 17*l.* 10*s.*; steel hoops, 18*l.*; and heavy sections of steel rails, 10*l.* 17*s.* 6*d.*—all f.o.t. makers' works. Whilst there are no fixed prices for export, they run approximately 40*s.* above home quotations.

LLOYD'S REGISTER AND ELECTRIC WELDING OF SHIPS.—With regard to the subject of the employment of electric welding in connection with ship construction, the Committee of Lloyd's Register, who have already approved one system of electric welding for the purpose, are prepared to consider applications from any electric welding companies with a view to their processes being recognised by the society, and to their names being inserted in a list of companies whose processes have been approved as fulfilling the society's conditions.

PAPER YARN AND THE COLD.—Some experiments described by M. Lummerzheim in the *Monatschrift für Textil-Industrie*, vol. xxxii, page 144, are of interest with respect to the storing and transport of paper yarn during the cold season. The yarn may contain up to 80 per cent. of moisture; exposed to the cold, such yarn loses strength and elasticity because the water freezes and weakens the fibre. When ice is seen to have formed on paper yarn and fabrics, the material should slowly be thawed, and the weaving rooms should not be allowed to get really cold. Suddenly subjected to frost, the yarn may be destroyed. It is, therefore, advisable to pack the yarn in such a way that the heat liberated by incipient freezing is retained and the rate of cooling is moderated. Hence yarn should be forwarded in closed boxes and covered railway wagons rather than in sacks and in open cars in which the wares are exposed to the cold and draughts.

NOTES FROM THE SOUTH-WEST.

CARDIFF, Wednesday.

The Local Markets.—There has been no development of particular note in the South Wales coal markets this week. The improvement noticeable in production last week has just been maintained, but there is room for still further improvement, and the feeling prevails, rightly or wrongly, that the miners are hardly exerting themselves to the extent necessary, especially bearing in mind the urgent appeals made to them. On the other hand it is pointed out that a heavy toll has been made on the miners for the Army, and that naturally those who have joined the Colours were of the best type physically, and that in these days, especially in view of the fact that the food supplies are not exactly what the men have been accustomed to, the same results on the average cannot be expected from the men who have remained in the industry. At the present moment, however, outputs just suffice to meet the demand, with the exception of the best grades of large steam coal. Inferior descriptions are plentiful, while there is quite an accumulation of small coals which are diverted to directions where they would not otherwise be sent under the Controller's zone system. Some difficulty is being consequently experienced in the matter of trains, but so far all the collieries are kept going.

Newport.—The boisterous weather has had a prejudicial effect on the shipment of Monmouthshire collieries, and some collieries are not sufficiently stemmed. The inland demand continues strong, and the best classes of coals are in the Eastern and Western Valleys, but inferior grades are plentiful. There is a fair supply of pitwood.

South Wales Coalowners' Pitwood Association.—Some idea of the splendid work accomplished by the Monmouthshire and South Wales Coalowners' Pitwood Association, which is the largest of its kind in the Kingdom, was given at the first annual meeting which took place on Monday. The first steps in the direction of the formation of the association were only taken in January, 1917, but by the present day the area worked by the association covers as much as 10,000 sq. miles. There have been purchased 210,000 tons of timber, and 143 woods of an acreage of 2,813 acres. No fewer than 57 woods have been cut and cleared, and 75 are still being worked. There are 750 workmen employed by the association, whose total wages bill amounts to 2,600*l.* a week, while there are 16 contractors employing 300 men employed in cutting woods. About 600 railway wagons are dealt with weekly, and the railway tolls amount to 72,000*l.* per annum; while the association lorries travel about 4,000 miles weekly. Mr. Finlay A. Gibson, the general manager and secretary, who organised the whole concern, felt compelled, owing to the increased duties now devolving upon him, to tender his resignation, and Mr. T. Rowe, the present commercial manager, was appointed to succeed Mr. Gibson.

EFFICIENT USE OF MOTOR TRUCKS IN THE UNITED STATES.—The amount of merchandise transported in motor trucks between cities in the United States is nearly double what it was for the same amount of travel before the war. This has been made possible by the return-loads method. This means carrying a load of merchandise in both directions on the truck. In other words, the car goes out with a load and comes home with a load. Formerly a motor truck carried a load in one direction only, it went out loaded and returned empty. Here is how the return-load method of operating motor trucks works out: Between two cities, such as New York and Boston, a distance of 225 miles, a motor truck delivers a load of soldiers' shoes from Boston to New York. Instead of returning to Boston without a load, the driver communicates with what is known as a return-loads bureau office in New York and asks if there is any New York merchant or manufacturer who has a load of goods to be transported to Boston. If so, he calls at the warehouse of this merchant, collects his load, delivers it to Boston, and charges a recognised tariff for the job. By this method, the truck owner not only cuts his own cost of delivery, but helps out in the present national necessity when the railroads give first care to war material. It is in long-distance motor trucking between such cities as New York and Philadelphia, a distance of 90 miles, where the return-loads method produces greatest results. Already, it is estimated that over 900,000 tons of war materials have been moved over this highway by motor trucks. Several companies are operating trains of motor trucks on schedules similar to those on which railroad trains are operated. There are a dozen other places in the country where motor trucks are being used over long distances for transporting war materials and merchandise and so ease the strain on the railroads. To-day many of the 144 concerns manufacturing motor trucks are selling large quantities to the farmers, who are using the trucks to move the grain from the farms to the railroads with greater speed, whence it is moved by railroad to the coast for shipment to Europe. Some makers are selling 60 per cent. of their trucks to the farmers. The advantage to the farmer of the motor truck is evidenced by the following example: One farmer with a truck has been able to move 600 bushels per day from his farm to the railroad station, a distance of 21 miles. His neighbour, using four horses, and two men, has only been able to move 200 bushels per day. The truck shows itself to have three times the capacity of the horse system, and only requires one-half the man-power. Man-power is short on the farm to-day, and the motor truck is making up for his shortage.

THE NEW QUEBEC BRIDGE.

(*For Description, see Page 277.*)

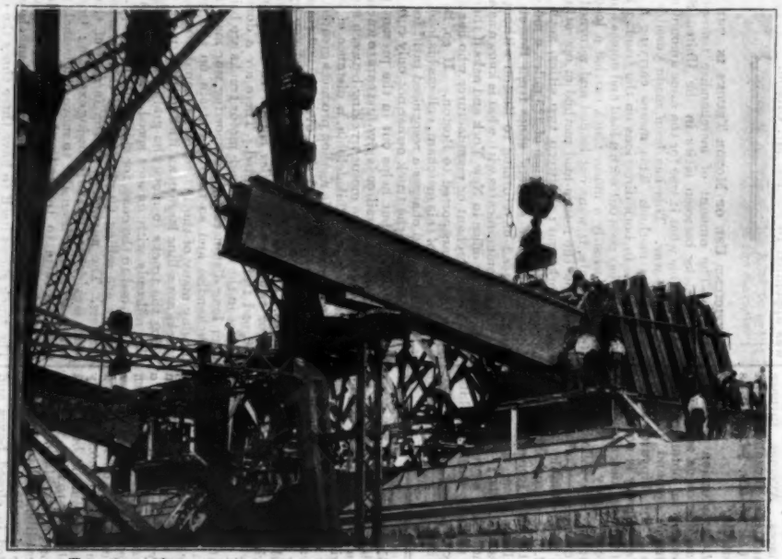


Fig. 24. Erection of First Element of Lower Chord of Anchor Arm.

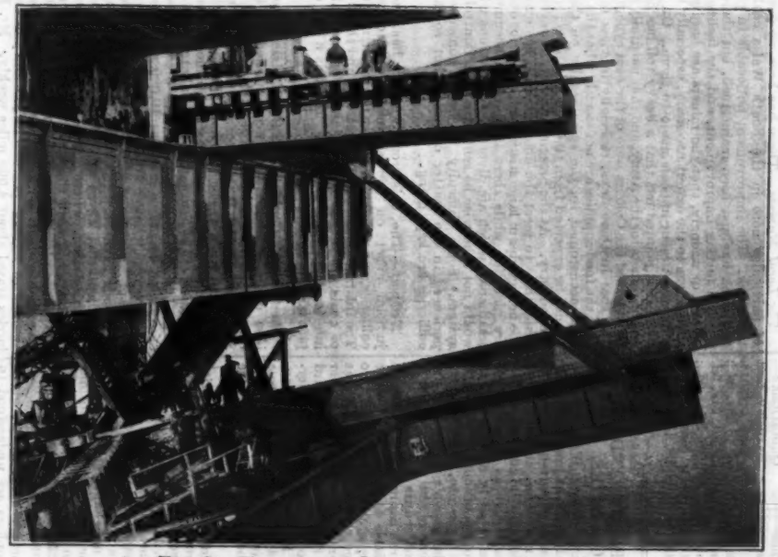


Fig. 25. Erection of Lower Chord of River Arm.

Fig. 26. Erection of First Element of Lower Chord for River Arm.

Fig. 27. View showing Flying Bridge supporting Chord Member in Course of Erection and the Lower Bracing Members.

THE NEW QUEBEC BRIDGE.

(*For Description, see Page 277.*)

Fig. 1. General View of Completed Bridge.

Fig. 2. View showing Test Load on Bridge, August 21, 1918.

(*To face page 276.*)

THE NEW QUEBEC BRIDGE.

(*For Description, see Page 277.*)

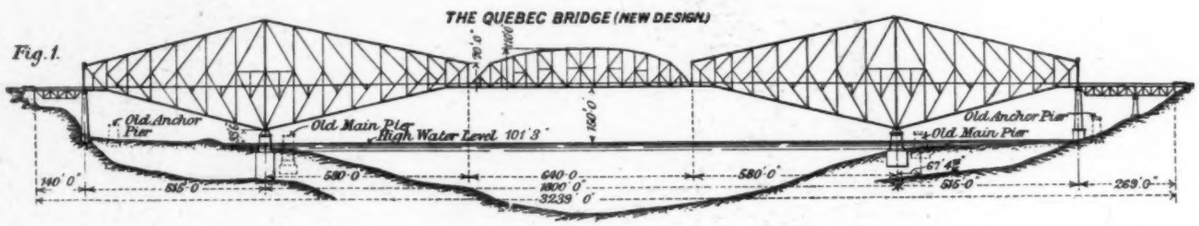


FIG. 3. DIAGRAMMATIC VIEW OF BRIDGE.

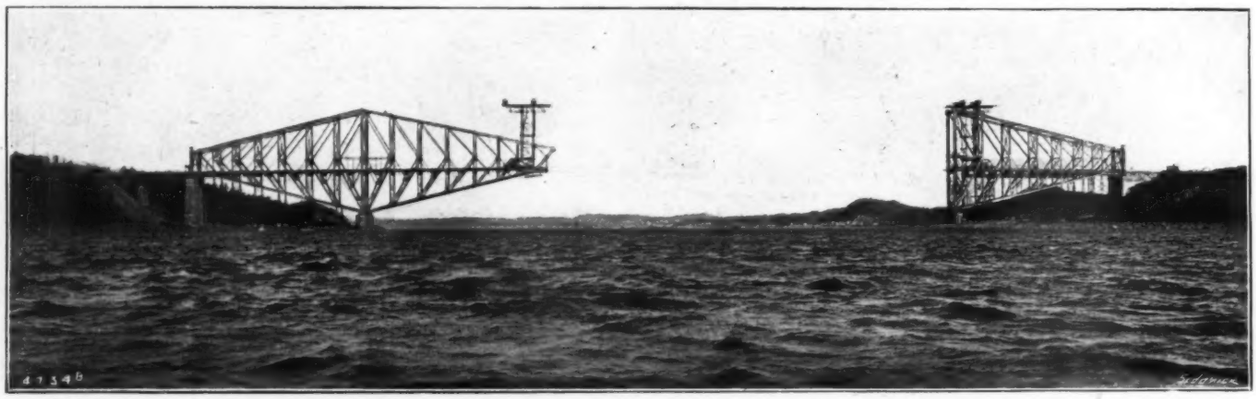


FIG. 4. VIEW LOOKING DOWN STREAM, NOVEMBER 8, 1915.

FIG. 5. ERECTING THE MAIN VERTICALS OVER THE PIER.

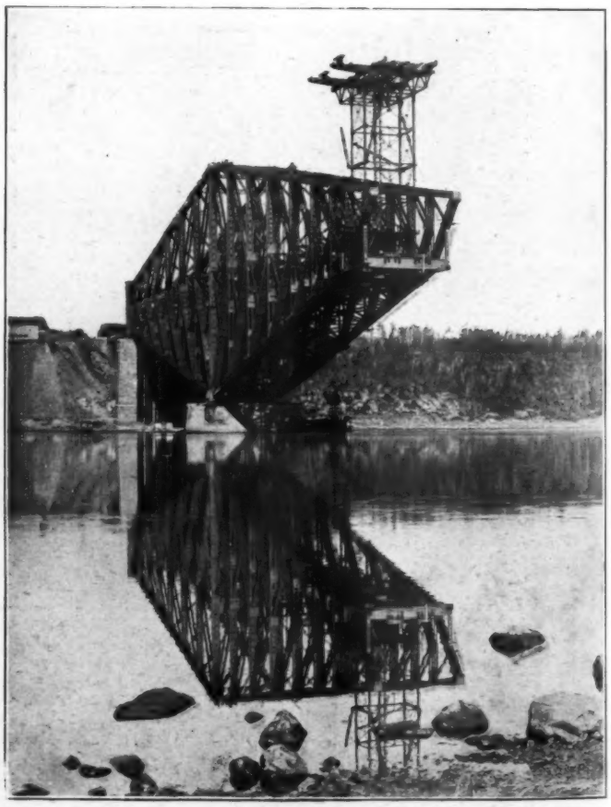


FIG. 6. VIEW SHOWING RIVER CANTILEVER COMPLETED.

THE NEW QUEBEC BRIDGE.

(*For Description, see Page 277.*)

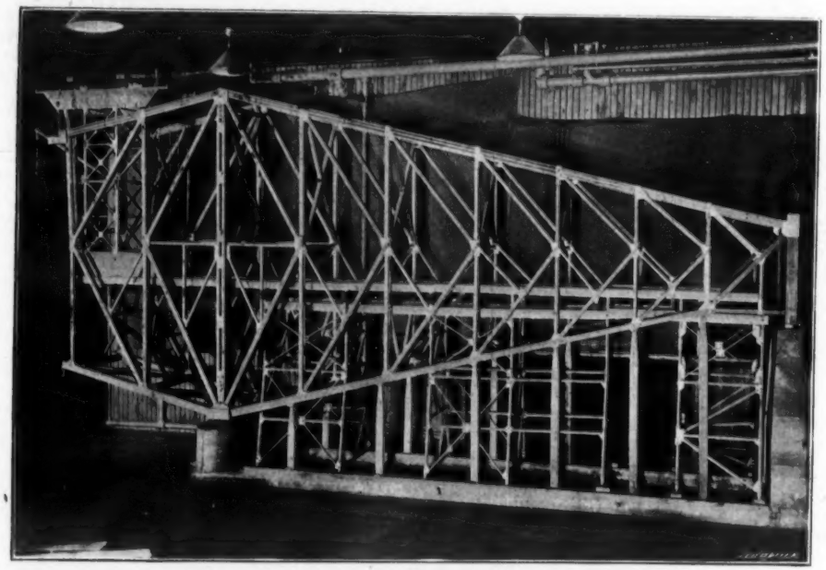


FIG. 7. MODEL USED FOR TESTING METHOD OF ERECTION.

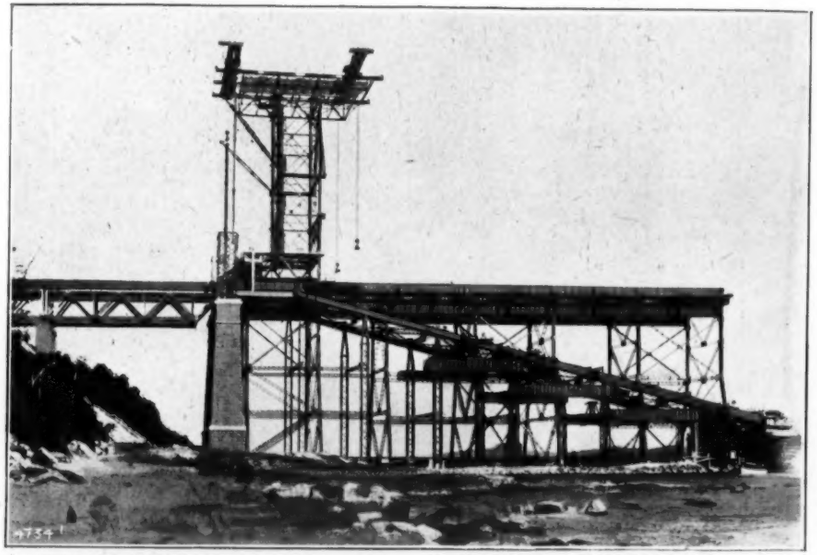


FIG. 8. VIEW SHOWING LOWER CHORD OF SHORE ARM FULLY ERECTED.

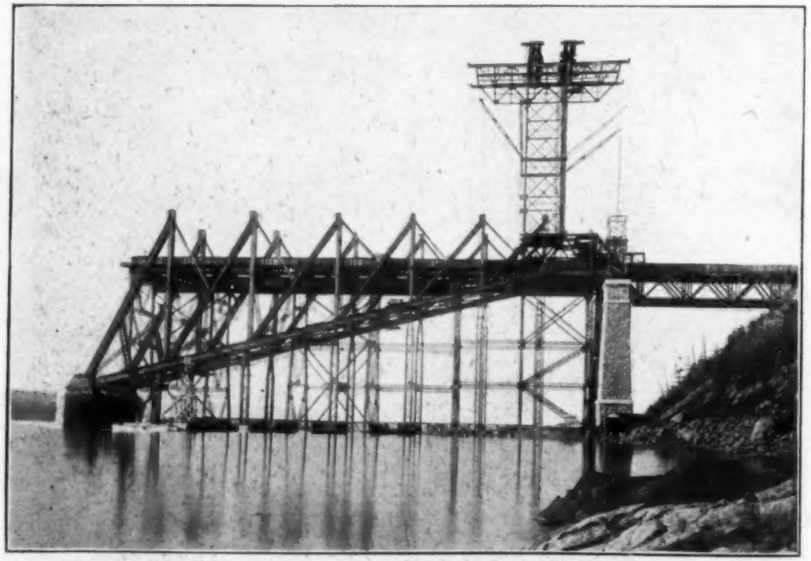


FIG. 9. VIEW SHOWING ERECTION OF THE LOWER PORTION OF THE K BRACING.

FIG. 10. SHORE ARM FULLY ERECTED.

THE NEW QUEBEC BRIDGE.

(*For Description, see Page 277.*)

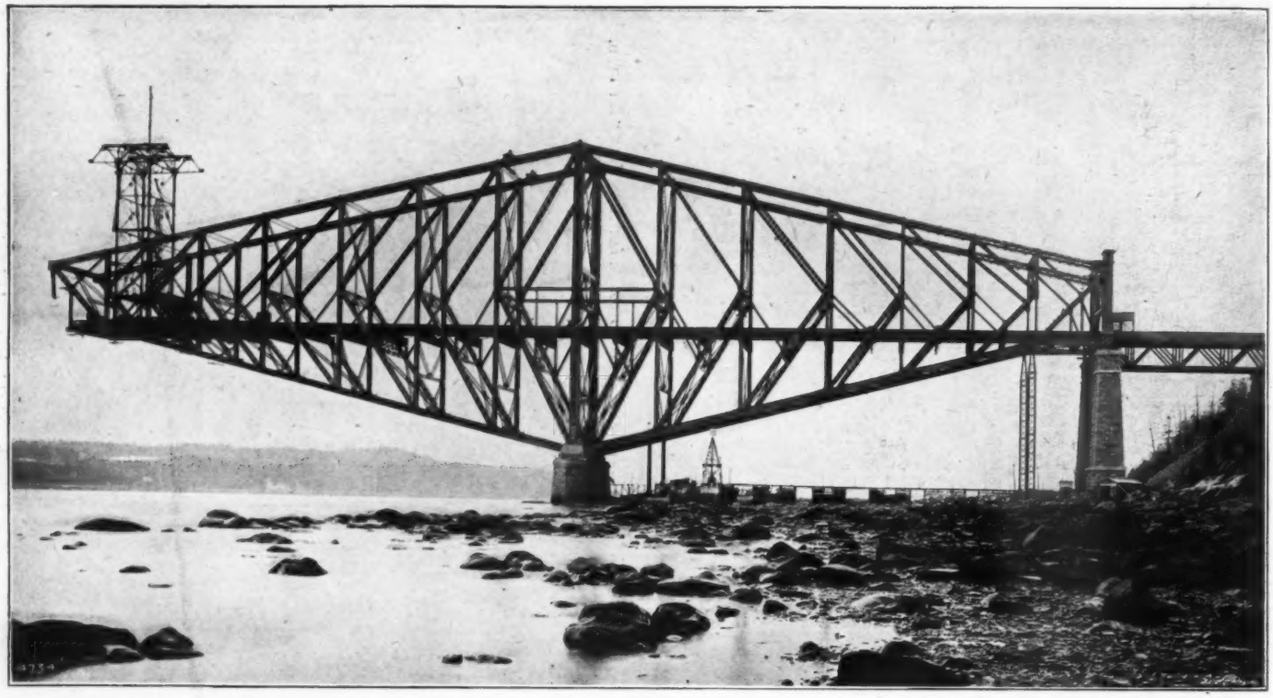


FIG. 11. RIVER ARM FULLY ERECTED.

FIG. 12. ANCHOR BARS IN COURSE OF ERECTION.

FIG. 13. MAIN TRAVELLER USED FOR ERECTING CANTILEVER ARMS.

(*To face page 277.*)

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Advertisements intended for insertion in the current week's issue must be delivered not later than 5 p.m. on Thursday. In consequence of the necessity for going to press early with a portion of the edition, alterations for standing advertisements should be received not later than Monday morning.

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TELEPHONE NUMBERS—3663 and 8598 GERRARD.

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With Four One-Page Plates of the NEW QUEBEC BRIDGE.

NOTICE.

Owing to the recent Government restrictions, and to the enormous increase in the price of paper occasioned thereby, the Proprietors of "ENGINEERING" are compelled to advance the price of this Journal further from 8d. to 9d. per copy. This increase dates from and includes the issue of Friday, March 1, 1918. The change will not apply to unexpired subscriptions. The revised rates for new subscriptions are given in the adjoining column.

NOTICE TO NON-SUBSCRIBERS.

In view of the restrictions now imposed by the Government on the importation of paper and the consequent shortage of supplies, Newsagents will not have copies for chance customers; therefore readers who wish to be sure of obtaining "ENGINEERING" each week should place an order for the Journal with a newsagent or bookstall clerk.

ENGINEERING.

FRIDAY, SEPTEMBER 13, 1918.

PERMANENCE OF STANDARDISATION IN MERCHANT SHIPBUILDING.

In attempting to arrive at some definitive view on this subject it is well at the outset to enforce the fact that the application of the principle of standardisation to the building of merchant ships is by no means a novelty to those acquainted with the work and methods of our leading builders of cargo vessels in pre-war days. To the majority of shipbuilders, however, consideration of the possibilities of the principle in the direction of expediting construction and lessening the cost of production was limited owing to the fact that orders for a number of similar ships were of very rare occurrence, and opportunities for the application of the principle did not arise. The urgent need for the most rapid production of new tonnage to meet the situation created by the war furnished the opportunity, and the action of the Shipping Controller in ordering the building of a number of standard cargo ships of various types and sizes has directed attention to the practical results of the application of the principle upon an extensive scale. Unfortunately the practical application of the principle—at least in the early stages and for a variety of reasons—induced grave doubts in the minds of many as to the wisdom of adopting the principle in its entirety. It is certain, however, that the difficulties and disappointments experienced in the building of the earlier standard ships were due to faults in application and not to any defect in the principle itself.

Under present conditions rapidity of production is by far the most important consideration bearing upon the shipping position, and any departure from established practice in regard to the design and construction of ships for the merchant service is justified only in so far as it increases the speed of production. There is no doubt, whatever, as to the beneficial effect on speed of production and cost of the adoption of a well-thought-out and efficiently operated scheme of standardisation, and the application of the principle to the shipbuilding programme of the present day and the near future needs no further justification.

After the war the main considerations bearing upon the merchant shipbuilding industry will undoubtedly be rapidity of construction and low building and running costs, the first two of which can undoubtedly be attained by standardisation. Low running costs involve the adoption of all improvements either of hull or machinery, and so are, in some degree at least, antagonistic to standardisation. Before the war a limited system of standardisation of hulls and machinery had been adopted by some shipbuilders and by certain of the shipping companies, but the number of ships so built was a very small proportion of the total.

From the shipbuilders' point of view the advantages to be gained by an efficient system of standardisation are many, of which the following are noteworthy: Owing to the handling of the same class of material yard plant may be reduced to a minimum amount and may be run at its maximum efficiency. Templates for the various parts of the ship's structure may be used indefinitely—sheet-iron being substituted for the usual wood of which templates are made. Workmen become specialists in the class of work undertaken, and should therefore produce work quicker and better than when dealing with different classes of material. The system lends itself well to the working and completion of the maximum amount of material on the ground and under cover, thus utilising the principle of "fabrication" and shortening the time of the vessel on the building berth. The above items all combine to achieve rapidity of output and low building costs, both of which are of prime importance.

The disadvantages from the builders' point of view are serious enough at first sight to condemn the project, and they have undoubtedly hindered its adoption in the past. The principal of these are: Uncertainty of repeat orders for any standard type; changes due to evolution of type or to improvements in hull or machinery. Each shipping company wants a standard type of its own. With regard to the first of these disadvantages, very few companies order more than one, or at most two, ships at one time, and in the case of those companies who make a practice of building new vessels at regular intervals it is usually found that each vessel is larger than the preceding one or is radically altered with regard to arrangements. Under the second disadvantage may be classed such structural alterations as those involved in the change from the ordinary transverse to the longitudinal system of framing and the structural changes involved in the change from reciprocating steam engines to oil engines for motive power. Under the third disadvantage may be grouped some of the disadvantages which weigh heavily against standardisation and which arise from consideration of the number and variety of trades which had been developed by shipowners prior to the war. Length of voyage, nature of cargo and number of passengers carried, depth of water at ports of call, cargo and coaling facilities available at ports of call; all these and many other considerations determine the dimensions and design of merchant vessels of all classes, and where more than one company is engaged in the same trade there is inevitably competition as to which shall own the largest and fastest vessels in the service. This competition leads to constant change in the designs of vessels built by any one company for a particular trade, and tends very directly to prevent any one type becoming standardised.

As regards design of hulls and speed of ships it is obvious that under normal competitive conditions but little approach to standardisation is possible, and if, as seems likely, post-war conditions rapidly become of the same competitive character the prospects for the general adoption of standardisation are poor. Propelling machinery of suitable power for each new design of vessel will be required, and here, again, the variety of powers required will preclude any standards being generally adopted. While the prospects of standardisation as applied to hulls and propelling machinery are thus very doubtful, there is no question that much could be done to standardise many of the deck fittings, &c., on vessels and much of the auxiliary machinery. Little has been done in this direction—particularly by shipbuilders—although the advantages are not inconsiderable. Bollards and fairleads, cargo winches, rail stanchions, cleats, eyeplates, cargo blocks and gear, and many other items of equipment are designed and made in infinite variety, thus involving much useless expenditure of labour and money. The preparation and adoption of standard designs for these details would be a very simple matter and would greatly expedite manufacture.

Conditions immediately after the war as regards the urgent necessity for new tonnage will probably be such that owners will be glad to order standard ships if these are reasonably near their requirements on account of the more rapid delivery of such vessels from firms now engaged upon that class of work. The severe internal competition which will subsequently have to be met by British shipping companies would, however, point to the conclusion that the only prospect of a real development in standard shipbuilding lies in the elimination of the com-

petition between shipping companies through the formation of combinations controlling within limits freights on all the main trade routes.

THE PRACTICIAN.

The assumption is often made that the practical man accomplishes by rule of thumb inferior results, while the technician is a superior being who arrives at superior results by analysis, deduction, logical thinking and scientific method. We are invited to believe that the day of the practician is over, that he is obsolete, while in industrial economics it is the technician who is to blaze the way to a better land. Scientific method having displaced rule of thumb, the despised and supplanted practical man should die quietly without any fuss and, like the corpse at a pauper's funeral, none need do him reverence.

One is afraid, however, that the practician will continue to elude extinction, and there is more than a suspicion that giants of the past, like Watt and Whitworth, were more practical than technical. Pure science pursues its own aims apart altogether from commercial considerations, the practician and technician both face the same problems, all of which have an economic basis.

The alleged separation between practice and technics and the presumed superiority of the latter is by no means so valid as the critics would have us suppose. It is upon practice that technics rest, and without the pioneer work of former generations who were unblessed with modern technical understanding, theory would have no foothold for there would have been no industry.

Two distinct view points are apparent, and both envisage the same end; the practician, if you will, looks from beneath and the technician from above, they meet in common in the resultant of their efforts, and it is by no means sure which has the superior claim to achieved success. The divorce between technical and practical is to be deplored, it has led to past misunderstanding, and on the part of the technician to an assumption of unwarranted superiority.

In engineering matters, definite and actual practice counts most, neither text-book nor laboratory experiment are a substitute, and real experience can only be obtained in close association with actual material things. No man is entitled to consider himself an engineer who has preserved his hands unsoiled throughout his career.

In too many instances where the technician has failed the practician has worried a way through a difficult problem to a satisfactory, if not an ideal issue. Native wit, experienced judgment, disbelief in precedent, and large doses of commonsense, are of greater value when the problem looks insoluble, than access to a reference library, formula or theory. The technician is apt to despise detail as something fit only for inferior brains, the practician lives, moves and has his being in practical detail and revels in his field. Detail wrecks more schemes than prime misconception, and for this reason there is, and will always be a wide field for the practician.

When novel conditions arise there are two courses open to determine the issue, by theoretical considerations awaiting the verdict of practical use; or to envisage the matter in the light of practical experience using theory as a check upon the intuitive practical belief. Where both sides are present in the individual responsible the second is the course usually followed. Practical results obtained, a theory is constructed in explanation. Theory is the explanation of practice more often than its basis, it co-ordinates more often than it originates, discuss the matter with any inventor for proof of this statement. In all essentials engineering folk are practical folk, more inclined to do than philosophise, commonsense is a wonderful guide to right practice based as it is upon proven experience. Academic knowledge is valuable, but in engineering matters usually has a constant, the result of practice to qualify its formulas.

A physicist recently pointed out that the knowledge of the trained engineer is not determinate enough, he is too prone to cut corners and not pursue knowledge for its own sake. It must be remembered that the life work of an engineer is to face and conquer actual practical problems, and his type of mind must be the reverse of the mathematician who lamented that his subject had a utilitarian end. There is a peculiar pleasure to be found in practical things, a practician feels it a personal disgrace if unable to overcome trouble met in daily work. If his solution be not academic it will usually fulfil its purpose in a rational manner. Temporary expedient, and unusual means are perpetual delights; they are proof of competence, affording as they do an opportunity for the exercise of talent on the part of the practician.

Most practicians have graduated at the college of the midnight lamp, even if they are unknown to any recognised academy. There are—to the everlasting credit of all ranks in engineering industry—few who have not some theoretical attainments. Many are the skilled mechanics who are able to discuss intelligently engineering problems from both the detail and constructional sides, all have abiding interest in mechanism, a large number are competent critics of design.

The practician is perhaps less vocal than the technician, but he is a vital force in industry, too apt to be overlooked in a casual or superficial assessment. The numberless unrecorded practical men who in a national emergency have performed marvels of substitution and expedient that the national cause should triumph, who have wrought miracles of production in the national interest merely serve to emphasise the value of the practician, for he is the man who, more than any other, has wrought system out of chaos, and reconstructed industry.

There is no real and valid distinction between the technician and the practician, they are complementary, not opposed; neither can claim real distinction over the other. Pure science is another matter entirely, industry must be greatly indebted to those who wrest natural law to serve man's need, it is the scientific side divorced from immediate utility which most often gives the starting point. Pure science is not technics, although its results may be so applied in numerous instances. To the practicians, therefore—whether technicians are covered by the same appellation or no—it is that industry and, in turn, commerce, must look, and to them, hard-headed and often horny-fisted, belongs the industrial future.

THE IMPORTANCE OF COKE HARDNESS.

With reference to a paper under the above title, by Mr. G. D. Cochrane, read and discussed at the last spring meeting of the Iron and Steel Institute,* it is interesting to note, according to *Le Génie Civil*, that Mr. Charpy and Mr. Godchot are at the present time carrying out a series of experiments on a large scale on the formation of coke. Following upon laboratory tests, they arrived at the conclusion that the most favourable conditions for obtaining a resistant coke implied different thermal treatments varying with the quality of the coal. In itself the determination of the most advantageous thermal treatment rendered it possible to utilise for the making of coke an appreciably greater number of coal qualities than was otherwise the case. Further experiments by the same French metallurgists have shown that when mixtures in variable proportions of two classes of coal, one too lean and the other too rich in volatile matter, are submitted to coking in identical conditions, it is found that the hardness of the coke obtained varies continuously and reaches a maximum for a given composition. Thus, mixtures were made using Brassac (South of France) coal containing only 11 per cent. of volatile matter, non-agglomerating when treated alone, with a Durham coal containing 24 per cent. of volatile matter, which yields a honeycombed and very friable coke. After treating the mixture at a temperature of 700 deg., which was found the most suitable temperature following upon preliminary tests, the hardness of the coke obtained was appreciable only when the proportion of British coal exceeded 20 per cent.; it reached 24 kg. per square centimetre (341 lb. per square inch) when the proportion of British coal was 25 per cent.; 45 kg. per square centimetre (640 lb. per square inch) when it was 44 per cent.; 80 kg. per square centimetre (1,137 lb. per square inch) when it was 51 per cent., and fell to 0 for the mixture containing 56 per cent. of British coal.

Maximum hardness corresponds with a percentage of volatile matter of 19·60 per cent. In the case of a mixture of two British coals, Durham and Cardiff, the maximum obtained was 70 kg. per square centimetre (995 lb. per square inch), the percentage of volatile matter being only 16 per cent.; with the same mixture, when the percentage of volatile matter was 19, hardness was practically nil. Instead of seeking to improve a too lean coal by mixture with another coal, volatile matter can be added to it directly by using coal tar pitch or tar.

The above-named 11 per cent. Brassac coal, to which coal-tar pitch is added, as soon as the percentage of volatile matter exceeds 14 per cent., gives a good coke, the hardness of which increases gradually and reaches 130 kg. per square centimetre (1,849 lb. per square inch) for a content of 28·8 per cent. of volatile matter, beyond which hardness decreases. The results obtained with additions of liquid tar are of similar nature; in some instances, however, the action of tar is more marked than that of the coal-tar pitch. Other tests had for their object to ascertain whether the coal which, containing a high proportion of volatile matter, yielding a honeycombed and friable coke, could be improved by a preliminary distillation at a low temperature; following upon trials, the temperature of 450 deg. was arrived at for this preliminary distillation. By maintaining the coal for a more or less long time at this temperature, its contents in volatile matter are gradually reduced. A gas rich in methane and a very liquid tar are evolved. Durham coal containing 28·1 per cent. of volatile matter and not suitable for coke-making, yields a coke of normal quality when it is made to undergo a preliminary distillation at 450 deg., followed by a treatment at 700 deg.; the preliminary distillation removes about one-third of the volatile matter.

* See Engineering, vol. cv, pp. 510 and 529.

THE INSTITUTE OF METALS.

The opening meeting of the autumn session of the Institute of Metals was held on Tuesday evening last in the rooms of the Chemical Society, Burlington House, the president, Professor H. C. H. Carpenter, F.R.S., occupying the chair. The following list of members nominated for the new council was read by the secretary:—President: Professor H. C. H. Carpenter, F.R.S. Vice-presidents: Mr. J. T. Milton and Professor T. Turner. Council: Mr. W. M. Morrison, Sir Charles Parsons, Mr. A. E. Seaton, Lord Weir and Mr. Arnold Philip.

The Cold-Working of Copper.

Mr. W. E. Alkins, B.Sc., next read a paper on "The Effect of Progressive Cold Work upon the Tensile Properties of Pure Copper." The paper, which we reprint in full in the present issue, described a series of experiments in which a rod of copper was in successive passes drawn down from $\frac{3}{8}$ in. in diameter to No. 19 S.W.G., there being 25 passes in all. The metal was not annealed throughout the whole course of the drawing, and its tensile strength was determined after each pass. On plotting this tensile strength of the copper as ordinate against the sectional area of the wire as abscissa, the resulting curve consisted of two straight lines connected by a nearly horizontal portion. The existence of this point of inflexion was confirmed by other experiments. The author expressed the view that his results could not be explained on the simple amorphous phase theory, and suggested that during the first stage the effect of the drawing was to give rise to an allotropic change in the metal; whilst the second portion of the curve could be explained on the lines of the amorphous phase theory.

The discussion was opened by Dr. W. Rosenhain, who congratulated the author on having brought to light a new fact which constituted a permanent addition to our knowledge. The author had, however, suggested that the amorphous phase theory of hardening was supported by qualitative evidence only. This was an error, as quantitative

data had been supplied by many observers as well as by those at the National Physical Laboratory. The author of the paper had given three reasons for selecting copper as the subject of his research. Of these the third seemed the most conclusive, viz., that the copper could be readily obtained. In other respects the choice was open to objection, since although the metal used contained only 0·08 per cent. of oxygen, this oxygen might exist as cuprous oxide. The eutectic of this compound with copper contained only 3½ per cent. of this oxide. Hence if all the oxygen in the copper existed in this form, the amount of eutectic might be 15 per cent. to 20 per cent. of the total. The speaker did not suppose the proportion was as great as this, but he would ask the author if he had examined his metal under the microscope, by which the presence of the eutectic could generally be detected, though it was, he admitted, not easy to see. If Cu_2O were present the metal experimented with could not be considered as typical of a simple metallic system, but would be a duplex substance, thus allowing of another explanation of the peculiarities shown by the experiment. The speaker would suggest, but merely suggest, that the oxide might be soluble in the amorphous phase, and that as new developments of the amorphous phase were formed by the deformation, this oxide would not be equally distributed and the properties at the crystal faces change accordingly. He had, however, no real objection to the theory advanced in the paper, but did think that Cohen had not proved the existence of his allotropic phase in copper. The author's suggestion was certainly an interesting one, and as allotropic phases were known to occur with some metals, the same might also be the case with copper, and the matter should receive attention accordingly.

Professor T. Turner, who followed, said that the author's paper was complementary to a previous paper by Pye, who had, however, dealt with copper from various sources, instead of adopting the more scientific procedure followed by the author of sticking to a single sample of the metal. The most interesting point brought out was the discontinuity in the curve of tensile strength. As a practical fact this had, however, been known for years, and was alluded to by Bolton in the discussion on Pye's paper. Practical men knew that there was a stage in the drawing of copper during which a considerable increase in the drawing down made very little change in the strength. It would be important to find out whether anything similar occurred with iron and nickel, which were known to be capable of allotropy, or whether copper formed an isolated case. If this were so the observation would not be nearly so important as if the peculiarity were general. He was interested in noting that the density of the metal in the state corresponding to the point of inflexion of the author's curve was 8·889 as compared with 8·9165 for the annealed bolt. In 1907, the speaker had, in conjunction with Dr. Levy, examined the volume changes produced by heating copper. They used a bar ¼ in. in diameter and about 1 m. long, and took autographic records of the volume changes. When they experimented on steel in a similar way the "arret" points (corresponding to the allotropic changes known to occur in this case) were clearly marked, but they found nothing of the kind either with annealed or hard-drawn copper. Both curves were smooth, the only difference being that the heating and cooling lines were a little wider apart with the hard copper. Since an allotropic change involved a rearrangement of atoms or of atomic groups, the change should be accompanied either by an evolution or an absorption of heat, and as there was no evidence of this in his curves he might say that the suggested allotropic change did not exist. Possibly a more sensitive method of experiment might show a result, but so far as they went the speaker's experiments were against the author's suggested explanation. Another possible view had been put forward by Dr. Rosenhain, and the speaker would suggest another. Copper crystallised in the cubic system. When deformed by cold working slip occurred across certain planes along which the metal became hardened. It was then no longer easy for further yield to take place here, but it might occur along other planes not necessarily parallel to the previous ones.

Professor C. A. Edwards said that he had a difficulty in discussing the paper without divulging other data since acquired by the author of which he had cognizance. The point brought out was of much practical importance, both to manufacturers and users, and might lead to trouble, since a cute maker might use the author's results to meet the requirements of a specification with a really inferior metal. As to the explanation of the anomaly, he was inclined to find it along the line suggested by Professor Turner, and to conceive that by the stretching, the character of the metal was changed, although this change was not of the type usually reckoned as allotropic, being merely a disturbance in the space-lattice of the crystallisation of the metal. He would further suggest that the anomaly noted might not be independent of the method of cold working, and that hammering might not have the same effect as cold drawing. Thus, although the author had found that cold drawing produced a marked change in the density of the metal, the speaker had failed to get any such change by compressing copper, even in cases in which the deformation had been very great.

Mr. C. H. Wingfield suggested that the anomaly discovered by the author might be responsible for the bell-hanger's practice of "killing" the copper wire they used. This they did by stretching the wire. At first the wire stretched easily and then suddenly stiffened.

Dr. C. H. Desch asked whether in drawing the wire any change took place in the character of the dies used or in the procedure followed.

Speaking on the invitation of the president, Professor Sakurai, of Japan, said that the supposed allotropic alteration of copper from an α to a β condition did not occur below the temperature of 71 deg. C., the α metal being the stable form below this limit of temperature. It did not therefore seem possible that the α metal could change to β metal in the process of cold drawing.

Mr. F. Johnson suggested that the experiments should be extended to determinations of the yield-point, elastic limit, and other physical properties of the metal in addition to its tensile strength; and, further, that other metals should be examined to see if in cold drawing them there was evidence of the same discontinuity as occurred with copper. As to the explanation suggested by Dr. Rosenhain, he thought that any concentration of oxide of copper in the sheath of the eutectic would cease on annealing, and that if the wire were annealed at each draw, its influence on the strength of the metal would accordingly disappear. He would suggest that the investigation should be repeated with copper rendered as free from oxide as possible. Certain de-oxidisers would effect this, with the result that the amount of deoxidiser left in the copper would be less than that of the oxide destroyed. In the discussion on Pye's paper the speaker had opposed the view that the hardening was a skin effect. Mr. Bolton took the same line and came to the conclusion that if anything the interior of the metal was harder than the skin. In Bolton's experiments, however, the process of machining must have had some effect on the skin, though not perhaps a very great one—still, the point required consideration before Bolton's results could be considered conclusive.

In reply, Mr. W. E. Alkins said that he had brought forward the explanation proffered of his results merely to round off his paper, and was quite prepared to admit that the problem was very complex. In fact, additional work done since the writing of his paper had convinced him that the view he had advanced would not cover the whole of the facts. With reference to the presence of oxygen he had not been able to use the electrolytic method of evaluating it, but would try and do this later on. He could say, however, that no eutectic was visible under the microscope. The investigation had originated in a peculiarity found in the drawing of bronze wire. At a certain stage in the drawing brittleness gave trouble. The wire was, however, not annealed, but the drawing continued, with the result that the ductility was recovered. When the idea of investigating this peculiarity arose, he had thought it best not to start on a duplex system like bronze, but with a simple metal. In reply to Dr. Desch, he might say that the dies used in the drawing were alike save that after a diameter of 0·072 in. was reached diamond dies were used in place of steel ones. With regard to the difficulty raised by Professor Sakurai he would say that in "cold" drawing, the temperature of the metal was raised so much that the workmen heated their food on the coil. It was thus much above 70 deg. C. He would try to make the additional tests suggested by Mr. Johnson, but he might say that the experiments on tensile strength had run into thousands. As to getting copper free from oxygen, if was fairly easy to get a billet oxygen free, but more oxygen was picked up during the rolling process, during which scale came down in lumps.

In bringing the discussion to a close, Professor H. C. H. Carpenter said that he had examined the work on the properties of copper issued by the Bureau of Standards, and in this authoritative and exhaustive treatise there was no note of the anomaly found by the author, which would thus seem to be quite a new discovery. As to the divergent views of Pye and Bolton, the Bureau had carefully studied the point at issue and found that the hardening effect was uniform across the whole section of the copper.

Impact Tests of Hardness.

Professor C. A. Edwards next read in abstract a paper on "The Resistence of Metals to Penetration under Impact." This paper is reproduced on page 285 of the present issue.

The discussion was opened by Professor T. Turner, who said that he had long held the view that static tests of hardness should be supplemented by dynamic tests. Martel's formula referred to in the paper was simple, and he thought was on the whole in better agreement with the results than the author's. He suggested that the results of dynamic tests would be a function of the speed and not merely of the energy of the impact. The anomalies found with respect to tin, cadmium and zinc, were, the speaker considered, important, and showed that the research was not a barren one, as it was the exceptions to a general law which most required study. He suggested that the peculiarity noted might have some connection with the value of tin as an ingredient of bearing metals.

Dr. W. H. Hatfield said that the author's method of investigation by experimenting would be of special value in high-temperature work. The section of the paper which showed that the hardness was a periodic function of the atomic weight was, he thought, a masterly production, but he would like to ask whether the carbon of which the hardness was plotted was considered to be in the diamond or in the graphitic form.

Mr. Alfred S. Barnes said that in connection with such tests as the author's and Brinell's it should be remembered that we knew very little of what was going on inside the metal below the indentation, and of the resistance of metals to flow. In the case of an ordinary test-piece it was easy to show that the shear was a maximum at an angle of 45 deg. to the axis of the applied stress, but the actual surfaces along which sliding occurred made with the axis an angle greater than 45 deg. if the test-piece were under tension, and less than 45 deg. in the case of compressive tests. Again, in a tension test the Luder's lines, which appeared just before the yield-point, had an inclination of about 60 deg. to the axis of the bar. Moreover, as the test was continued and local deformation set in a "contractile cross" due to the flow could be detected, consisting of two grooves making an angle of 65 deg. with each other. In the Brinell test the rate of deformation was slow, but from Hopkinson's results the duration of the impact in the author's experiments would be about $\frac{1}{10,000}$ second, and during this short interval of time all sorts of things took place. To get some idea as to what these phenomena were, the speaker had experimented on the effect of impact applied to brittle materials such as glass, flint and pitch. Under the impact of a spherical ball on to one face of a glass cube a conical fracture was produced below the surface struck. The angle of this cone ranged between 90 deg. and 120 deg. In other cases the surface of fracture was a rectangu-

lar pyramid with an apex angle lying between 45 deg. and 90 deg. In another series of experiments he had built up a number of 3-cm. cubes consisting of superimposed layers, in one case of plasticine and in the other of indiarubber. Between the layers a sheet of tin foil was interposed. On subjecting these built-up cubes to impact and examining the foil, it appeared that in the case of the uppermost sheet the centre was disintegrated, and a hole about equal to the diameter of the ball produced. Around this was a layer which had undergone compression, as proved by the imprint on it, of the rough surface of the rubber sheets between which it lay. In the case of sheet No. 2 the central hole was about the same size as in the case of sheet No. 1, and was again surrounded by an area of compression. Beyond this was an area in which the foil had been buckled into corrugations. These observations showed that in such tests as the author's all sorts of things were going on in the metal besides the mere making of an indentation.

Mr. Cosmo Johns said that he considered the relationship noted between the hardness and the absolute melting temperature as a point of the utmost importance. He would ask, however, that the authority for the melting-points should be given. He would also suggest that the author should plot his results not against the atomic weights, but against the atomic numbers, which were a more fundamental property of the atoms. The position of cobalt and nickel would then be reversed and the curves made more concordant. Whether the author was really measuring hardness was, however, another point. Shore, he observed, considered that the sceleroscope measured the elastic limit and the Brinell test the tenacity of a metal. The speaker himself thought that in all these tests, as in the author's, what was measured was not hardness but a parallel property. In impact tests Kipp had shown that it was important to use the hardest possible substance for the striker, and he would suggest to the author the possibility of modifying his apparatus so as to use a diamond striker. Further, he thought that in tests of this kind the aim should be to determine not the amount of indentation produced, but the energy which would just fail to indent the metal.

Colonel Sir Henry Fowler thought the author's method of experimenting might give highly useful results if applied to the aluminium alloys used in aeroplane work. He would like to ask the author if he could say where the displaced metal went to in such tests and how he measured the volume of the indentation.

Dr. W. Rosenhain said that the anomalies found with tin, zinc and cadmium, constituted a point of interest. The author suggested that twinning was responsible for this, but did he find similar anomalies with copper, silver and gold, which twinned readily? He would suggest that another peculiarity might be connected with the anomalous positions of tin, zinc and cadmium. Tin gave a "cry" when deformed, and to a lesser extent so did zinc and cadmium. So far as he knew these were the only three metals that had a "cry." In discussing such experiments the fact that flow was produced was important. Flow required time. Pitch, for example, fractured under a blow but flowed readily under a steady pressure. To a certain extent this was the case also with glass, both being under-cooled liquids. With metals, however, we had to deal not with under-cooled liquids but with crystalline aggregates, which, however, could by the action of strain be transformed into an under-cooled liquid known as the amorphous phase. On the viscosity of this amorphous material would depend the difference between slow and rapid deformation. With large viscosities the deformation would be relatively less in impact than in static tests. When near the melting point, however, the mobility of the amorphous phase became high and the conditions would then be materially altered. The relationship brought out between the absolute melting point and the hardness was very important, and he might note that the connection between the melting point and other physical properties of metals had been carefully studied in America by Richards.

Dr. Smith said that the author's table of hardness was the first to be published since 1873, and the older table was, in his opinion, so "smooth" as to raise suspicions as to its reliability. Whatever the property measured by the author might be called, it was noteworthy that it was closely connected with the melting point, and this fact was additional evidence that we were concerned here with a fundamental property. The author's curve seemed to him superior to that obtained by Lothar Meyer on plotting atomic volumes. He believed that the property of hardness was connected with the cohesion of a metal as measured by the surface tension when molten.

In reply Professor Edwards said that the possible effect of differences of striking velocity to which Professor Turner had referred was insignificant in the speaker's case, as the range of velocity was small. As to Dr. Hatfield's question *re* the condition of the carbon he had purposely refrained from stating it, but he believed the carbon was in the diamond form. The melting points he had taken as far as possible from the treatise of Burgess which gave the most reliable and up-to-date figures. He was glad to have Mr. Cosmo John's suggestion to plot his results against the atomic numbers instead of against the atomic weights. As to what was meant by hardness, it was true that his results did not correspond to those obtained in the scratch test, but his own, Brinell's and the sceleroscope figures were all simply related together. He might add that he thought that the sceleroscope could be modified so as to combine all its own advantages with those of the Brinell method, and of the method described in his paper. It was not easy to answer Sir Henry Fowler's question as to where the displaced metal went. As to Dr. Rosenhain's observations on twinning, he would say that tin cadmium and zinc all twinned when deformed, and this twinning was responsible for the "cry." The other metals, copper, silver and gold, were generally held not to twin merely by deformation. If they did, it was a bad look out for the slip band hypothesis.

In adjourning the meeting till the next afternoon, the President expressed his pleasure and surprise that a practical steel maker like Mr. Cosmo John had found time to study such purely scientific work as that of Moseley on atomic numbers. It was, he thought, a most significant sign of the times in which we lived.

(To be continued.)

NOTES.

THE IRON AND STEEL INSTITUTE.

THE autumn meeting of the Iron and Steel Institute opened yesterday, and is being continued to-day, in the hall of the Institution of Civil Engineers, under the chairmanship of Mr. Eugéne Schneider, president. The papers on the list number seventeen, which is highly creditable to the contributors, practical metallurgists, analytical chemists and scientists, who are still extremely busy in supplying the nation's and Allies' needs in war material of all kinds. The first paper taken at yesterday morning's meeting was the one by Mr. G. Charpy, on "Influences of Hot Working on the Qualities of Steel." It was followed by contributions from Mr. A. McWilliam, on "Influence of Elements on Tenacity of Basic Steel," from Mr. A. J. Shore, "Report on Hardness Testing" and from Mr. Cosmo Johns, on "The Standardisation of Tests for Refractory Materials." The usual full report of the proceedings will be published in our next issue.

THE STANDARD SAYBOLT VISCOSIMETER.

Mr. Winslow H. Herschel has continued his work on Absolute Determinations of Viscosity, which we noticed in an article under that heading on page 655 of our issue of June 14 last, and in sending us a reprint of his further paper—which has meanwhile been read before the twenty-first annual meeting of the American Society for Testing Materials at Atlantic City—he kindly draws attention to a slight error which had been overlooked in our account just mentioned. A division line had been left out in the formula, originally due to Couette, for the kinematic viscosity; $m\,v^2\,g$ had been printed in the place of $m\,v^2/g$. We had given Bingham's modification of Couette's formula, using the symbols adopted by Higgins and others in this country. Bingham himself wrote his formula for the viscosity:

$$\eta = \frac{\pi\,g\,r^4\,P\,t}{\gamma\,V\,(l+\lambda)} - \frac{m\,\rho\,V}{8\,\pi\,t\,(l+\lambda)}.$$

As regards the new research, negotiations have taken place between Mr. George M. Saybolt and the Bureau of Standards, and the dimensions and allowable variations agreed upon for the standard Saybolt universal viscosimeters are tabulated by Mr. Herschel as follows; the min., norm. and max. mean minimum, normal and maximum :—

Dimensions in Centimetres.	Min.	Norm.	Max.
Outlet tube, diameter inside d ..	0·1750	0·1765	0·1780
Outlet tube, diameter outside at lower end d_2	0·28	0·30	0·32
Outlet tube, length l	1·215	1·225	1·235
Height of overflow rim above bottom of tube h_1	12·55	12·60	12·65
Average head h (calculated) ..	7·32	7·41	7·61
Container diameter D	2·955	2·975	2·995

The average head h is calculated from $h = (h_1 - h_2)/\log(h_1/h_2)$, where h_1 and h_2 are the initial and final heads respectively, and the log. are natural logarithms; this equation is not accurate except for very viscous oils. Since 60 cub. cm. are run out during a test, $\pi\,D^2\,(h_1 - h_2)/4 = Q = 60$; h is therefore partly determined by the container diameter D which has to be specified as an essential dimension. The dimensions recently adopted differ from those of the instruments Herschel had used in his first paper; hence the new research. In this Herschel makes use of the following formula for the viscosity in poises/density in grams per cub. cm.: $\mu/\gamma = A\,t - B/t$, where t is the time of discharge in seconds, $A = \pi\,g\,d^4\,h/128\,Q\,(l+\lambda)$, $B = Q\,m/8\,\pi\,(l+\lambda)$, λ the Couette correction for the effective tube length, and m the coefficient of kinematic energy. The λ and m are determined to find the A and B. If the ratio of viscosity to density were accurately known for suitable liquids, A and B could be deduced without having recourse to the formulæ given. We commented previously on the difficulty of finding a suitable liquid. Herschel adopted solutions of ethyl alcohol in water, although they are only available over a limited range. The final formula deduced for the Saybolt viscosimeter is: $\mu/\gamma = 0.00220\,t - 1.80/t$. This expression holds for the normal dimensions stated. In the case of the allowable minima, the coefficients change into 0.00211 and 1.82, for the allowable maxima into 0.00230 and 1.79. These values replace those formerly in use, which were acknowledged to be only approximate. The paper also compares the new values with the constants of the Engler viscosimeter.

THE QUENCHED SPARK.

Text-books on radiotelegraphy deal with the phenomena of quenched sparks in a rather superficial way, and an adequate explanation of the phenomena, indeed, does not appear to exist so far. Max Wien himself, the discoverer of the quenched spark system, and the early investigators of the novelty of 1906, were chiefly interested in finding the most suitable experimental conditions for efficient quenching. A noteworthy experimental and theoretical contribution to the study of quenched sparks is made by Dr. V. Pieck, of Goettingen, in the "Annalen der Physik," of February 22, 1918, pages 197 to 244. Pieck describes the method of quenching as follows: Two electric circuits of equal frequency are loosely coupled so as to form one system capable of oscillating at two main periods, the one of higher, the other of lower, frequency, than the original. One of the circuits comprises a spark gap; when this circuit is charged until the spark passes, the two oscillations are excited, beats arise, and the energy oscillates between the two circuits. With a very small spark gap the spark current may be interrupted momentarily, when the energy has completely passed over to the second circuit; the energy cannot return to the first circuit, therefore, and will continue to oscillate in the second circuit at the latter's period, as if the first circuit were not in existence. Pieck goes back to Roschansky, who, in his researches of 1912, regarded the phenomena as those of a high-frequency

alternating arc, whose tension is of the nature of a counter electro-motive force e_0. Immediately after the current reversal, and when the current intensity is still about zero, this e_0 climbs up to, say, 400 volts, to fall off abruptly at the next moment to a few tenths of a volt; thus, the curve of e_0 forms a sharp, high-ignition peak. The e_0 then keeps fairly steady, while the current i rises and diminishes again, until the next reversal takes place, when a new electro-motive force e is applied; if this e be strong enough to overcome e_0, the discharge will continue; but if $e = e_0$, $i = o$, and also di/dt equal or smaller than zero, the spark will be extinguished. Pieck accepts this view on the whole, but he points out that Roschansky, when dealing with the frequency and phase difference, which depend upon the degree of coupling, treated the phenomena as practically static, whilst they are dynamic. Pieck studied the influences of many factors largely with the aid of oscillograph curves. He worked with electrodes of magnesium or silver, two cylindrical rods, up to 1·5 cm. in diameter, two plane discs or a disc and a rod, in air, nitrogen, carbon dioxide, hydrogen, at pressures ranging from about 100 mm. up to 750 mm. of mercury, and he varied the frequency in the ratio of 1 : 15, experimenting with waves of lengths from 120 metres up to 2,140 m. He found that the quenching effect was, approximately, the same with magnesium electrodes in air, nitrogen and carbon dioxide, but decidedly better in hydrogen. Silver gave much better results than magnesium, especially at low gas pressures and with small spark gaps, in nitrogen; in a hydrogen atmosphere, however, the observations were rather discordant. At high gas pressures low or high frequency made little difference; at low gas pressures (nitrogen or hydrogen) short waves proved more effective for quenching than long waves. Having discussed the theory at some length, considering also the influence of the ionisation of the gas and of the recombination of the ions, Pieck points out that at low gas pressures the discharge potentials do not any longer increase with increasing spark length, but tend to decrease. Many not yet mentioned factors have to be considered, and he sums up that the chief requisite for efficient quenching, a high peak in the electromotive force, is, in general, obtained by small current amplitude and low frequency and by high thermal conductivity, large cross-section, and a large product of density and specific heat of the electrodes. The electrodes should not become incandescent; the ionisation potential of the metal, the mobility of the ions and their recombination-coefficient should also be high; the gas pressure should be low although, within certain limits, high gas pressure and long sparks offer advantages. These conditions are, to a certain extent, incompatible with one another. The research was conducted under Professor T. Simon.

INDUSTRIES IN JAPAN.—A great industrial development has taken place in Japan since the outbreak of the war. Eighty firms are engaged in the manufacture of artificial dyes; they are mostly sulphur colours, but aniline and miscellaneous colours are also manufactured in considerable quantities. Ultramarine used to be imported from Germany; the United States then stepped in, and a home industry is growing up in that branch as well. With the general development and the war requirements the demand for asbestos has increased enormously. Japan now manufactures asbestos ware, and the imports of the raw material from Canada by the 11 companies were ten times as large in 1916 as in 1914, in spite of an import duty. The domestic asbestos manufacture is also important.

IRON IN POTABLE WATER.—Our soldiers at the front have had reason to complain about the water of Flanders. From a paper by O. Beck, in the *Zeitschrift für Angewandte Chemie*, 1918, pages 115 to 116, we see that similar troubles have been experienced in Antwerp. The deep-well water there is good, but much of the supply is moorland water which contains iron in the forms of bicarbonate and ferrous sulphate. To remove the iron, the water was first treated on Schäffer's system with blood charcoal containing 16·6 per cent. of aluminium sulphate and then sent through Dunbar filters; the aluminium gave the water an unpleasant taste after standing, however, and the filters became clogged. The method which Beck recommends is not simple, and frequent renewal or disinfection of the filters is still advisable. The treatment consists in mixing the water with hydrogen peroxide, which is added in small quantities, agitating the mixture, adding finely-powdered soda, and filtering off the precipitate which settles in about half an hour.

LITERATURE.

Handbook of Ship Calculations, Construction and Operation. By CHARLES H. HUGHES, Naval Architect and Engineer. London: The Library Press, Limited, 36, Portugal-street, W.C. [Price 22s. 6d. net.]

To the small but exceedingly useful number of pocket books dealing with the theory and practice of shipbuilding, of which Macrow's and Simpson's are outstanding examples, there now falls to be added the "Handbook of Ship Calculations, Construction and Operation," by Mr. Charles H. Hughes, a volume which gathers within its 740 pages an immense amount of practical information of great value to all those interested in the design, construction and maintenance of ships and their machinery and fittings. The primary function of all such pocket books is to provide the busy man with such information as he may require in a form which bears directly upon the problem in hand and which, in its application, does not require the knowledge and use of advanced mathematics. This important consideration has been adequately realised by the author throughout, and as a result the range of usefulness of the volume is extended to include the very numerous class whose interest in shipbuilding and engineering is purely on the practical side. The scope of the work is such that it embraces practically all important branches of the shipbuilding and engineering industries as well as problems connected with the maintenance and operation of ships in service, chartering, marine insurance, &c.

The section dealing with ship calculations contains a mass of useful information in convenient form and covers not only the usual calculations of displacement, centres of buoyancy, trim and stability, but also the determination of freeboard for various types of vessel, launching calculations and data, and determination of horse-power. The tables of hull and machinery weights might with advantage have been included in this section, as also might the chapter on Structural Strength, as these belong properly to the design office.

Hull construction is treated in a more comprehensive manner than is usual in this class of book—both war and merchant vessels being dealt with. Transverse and longitudinal systems of framing are described and illustrated, and details of all the more important items of structure given. Such varying types of merchant vessels as oil tankers, trawlers, bucket and suction dredgers, are dealt with, while the characteristics of each class of war vessel are concisely and clearly stated. In his general description of torpedo boats the author states that the longitudinals are intercostal, but in view of the fact that the main longitudinals (those forming engine and boiler girders and which extend over fully 50 per cent. of the length of the vessel) are continuous—the statement is misleading. In speaking of armour the author states that the side armour has a cement backing. As this is one of the most recent developments it would have been of value if the author had given details of thickness, composition, weight, &c., of this backing in comparison with the teak backing which has been universal hitherto. The paragraph on Battle Cruisers gives the secondary armament of H.M.S. Tiger as sixteen 4-in. guns and three torpedo tubes, while the breadth of the ship is stated to be 87 ft. The corresponding figures given by Mr. E. L. Attwood in his "Warships" are: Twelve 6-in. guns and four torpedo tubes, and breadth 90 ft. 6 in. It is noted that no sketch of the spade type of rudder for warships is given, though this is now much more common than the ordinary balanced type illustrated, and that the figures for ratio of rudder area to lateral plane are on the whole rather in excess of British practice where the highest ratio —in torpedo-boat destroyers—is about 2·2 per cent. for balanced rudders.

Details of the construction of wood vessels are also given. An interesting table of prices of steamships sold during May, 1915, and May, 1916, is given in the section dealing with prices, costs and estimates, while figures for the building and operating costs for a 225-ft. motor schooner are given in detail. From the list of sales given we take the following figures as showing the appreciation of merchant tonnage as a result of the war. During May, 1915, the sale of 11 vessels over 5,000 tons deadweight and totalling 71,750 tons, realised 542,000*l.*, an average of, roughly, 7·56*l.* per ton deadweight. During May, 1916, the sale of 14 vessels over 5,000 tons deadweight, and totalling 90,545 tons, realised 1,863,000*l.*, an average of about 20·25*l.* per ton deadweight. The cost of building a 225-ft. motor schooner of 1,125 tons net, fitted with two oil motors, each of 160 i.h.p. and capable of a speed of 7 knots loaded, vessel built during 1916 on the Pacific coast, is given at 128,100 dols. The operating cost per day for ship and engines is given at 110·95 dols. and for engines alone 14·26 dols.

An important section of the book deals with boilers and propelling machinery, also the auxiliary machinery of the engine and boiler rooms, and here again there is much information of great practical value. Types of boilers are described and illustrated, and details of systems of oil-fuel burners are given. Details of boiler fittings, air supply to furnaces and much other information of a useful nature are given, together with practical notes on boiler management. Propelling machinery described includes reciprocating engines, turbines (including geared turbines), paddle engines, the turbo-electric system, and internal combustion engines, and these, together with their auxiliaries, are dealt with in detail. In discussing types of propelling machinery the author gives comparative figures of cost of carrying freight per ton in the case of vessels with (*a*) reciprocating engine, (*b*) geared turbine, and (*c*) oil engine. The ship in each case is 400 ft. between perpendiculars by 52 ft. by 29 ft. 9 in., and has draught of 26 ft. 1 in., the deadweight carrying capacity in tons, with the different types of machinery, being respectively (*a*) 7,880, (*b*) 7,910, and (*c*) 8,530. At a speed of 10½ knots, radius of action is 3,500 miles; fuel consumption in case of (*a*) 1·6 lb. per indicated horse-power per hour, (*b*) 1·2 lb. per indicated horse-power per hour, and (*c*) 0·61 lb. per indicated horse-power per hour; while the carrying costs work out at 1·33 dols., 1·30 dols., and 1·25 dols. per ton respectively. The author's general conclusion is that at the present state of development, Diesel engines are not suitable for high-powered vessels from engineering rather than economic reasons, and with this conclusion we are in agreement. The comparative data given in the case of vessels driven by turbo-electric machinery and similar vessels driven by turbines and reciprocating engines is not sufficiently detailed to enable comparative efficiencies to be estimated and the author wisely limits his comments to a statement of the claims made for the former system.

The section dealing with electricity contains details of systems of electric wiring adopted on United States battleships, &c.; construction and fittings of switchboards; lay-out of electric installations in accordance with American practice; details of motors installed in United States warships for various duties and other information of a general character.

Sections dealing in detail with Heating; Ventilating; Refrigeration; Drainage; Plumbing and Fire Extinguishing; also Ship Equipment and Ship Operating, are included in the volume, and each contains information of a highly practical and useful character.

The notes on loading and stowages of various cargoes with a view to ensuring stability should be of especial interest to ship's officers and are of such a nature as to make them easily understood by all.

Mr. Hughes has undoubtedly produced a book which should appeal particularly to the very large class who desire data derived from and therefore directly applicable to practical problems connected with all the phases of shipbuilding, engineering, ship maintenance and operation, and to all such the book which is admirably produced and printed, can be highly recommended.

BRITISH SCIENTIFIC PRODUCTS EXHIBITION.—ERRATUM.—We regret that a mistake has been overlooked in the concluding remarks of our article, published on page 251 of last week's issue. The twentieth line from the end of the article should read:—except that the Board of Trade loaned [*not* boomed] some cases.

INDUSTRIAL NOTES.

SPEAKING at Bromley (Kent) last Monday, with reference to demobilisation, Mr. Roberts, Minister of Labour, said he intended to make it quite clear that he would not have any dealings with a haphazard solution of the problems. He would retain the splendid fellows in the Army much longer than they might appear to think necessary rather than release them in a haphazard manner to swell the numbers of unemployed. The men would be released only when a reasonable assurance was forthcoming that industry was capable of absorbing them and that they could be permanently settled in civil life. The first to be demobilised would be the men whose employers had promised to reinstate them; he favoured modifications for married men against single, and for volunteers against conscripts.

The Gas Committee's report for Walsall for the past year shows the gross profits to have amounted to 15,765*l.*, against 16,816*l.* in 1917 and 19,694*l.* in 1916. The increase in the cost of coal was 46¼ per cent., and the increase in wages 57½ per cent. The committee's chief source of anxiety now was with regard to the coal supply for the ensuing winter, and they had very grave doubts as to whether the supply of gas would be maintained over a most important period of the year if existing conditions did not improve. Twelve months ago they had 9,000 tons of coal in stock at the gas works; to-day they had only 300 tons, or about a three weeks' supply. Last year they had about 400 tons of coke in hand; to-day their stocks had run out.

The Electric Supply Committee's accounts showed that the undertaking had made a gross profit of 13,949*l.*; payments for interest and sinking fund not only wiped out this amount but left a deficit of 3,998*l.*, which, with a deficit of 8,988*l.* brought forward from last year, made a total loss of 12,986*l.*, towards which 4,000*l.* had so far been paid out of the rates. With regard to the balance of 8,986*l.* a claim was to be made against the Ministry of Munitions. In view of the increase in the cost of coal it had been decided to increase the price of electricity by 10 per cent. The Gas Committee also contemplated increasing the selling price of gas.

A letter from a legal correspondent, on "The Education Act and Industry," in *The Times Educational Supplement*, contains a number of figures which are interesting. The census of 1911, the letter says, showed that of the 2,812,433 children between the ages of 10 and 14 years, 146,417, or 5 per cent., were occupied. The boys numbered 97,141, or 6·9 per cent. of the total of boys, and the girls 49,276, or 3·5 per cent. of the total of girls. Of the boys, 24,870 were messengers, and 23,399 were employed in textile manufactures. Eight thousand boys were engaged in coal mines, and 7,800 were agricultural labourers. Out of 3,880 boys occupied under 12 years, 1,756 were newsboys and 1,660 messengers. These two occupations together with the textile industry found employment for most of the boys who were occupied between 12 and 13 years. More than half of the total number of occupied girls under 14 were employed in textile manufactures. Full-time school attendance up to 14 years will deprive the textile industries of services which they had hitherto received from more than 48,000 boys and girls.

By far the largest number of young persons begin work at present between the ages of 14 and 15 years. Thus, in 1911, at 14, more than 147,000 boys and 130,000 girls entered upon occupations. The figures at 15 years were, boys 55,000 and girls 193,000. At 16, the figures were, boys 25,000 and girls 225,000. Above this age, the number of persons who enter occupations diminishes rapidly.

The figures of occupied young persons up to the age of 18 years suggest an extremely large reduction under the new Act of the energy which has hitherto been diverted into a number of industries.

The Act, the correspondent states, aims at the production of an industrial population which will be superior to that with which employers have hitherto had to deal. The problems which it creates are manifold and at present insoluble. The cost will be great to the industries of the United Kingdom, but it should be in the nature of a national investment. The statute, however, is an adaptable one in many respects; unless it were, it would fail in its objects.

The same journal contains another communication showing the results of the Cambridge University Local Examinations held in July. The candidates are boys and girls under 18 from secondary schools all over the land. The correspondent, who has watched these lists for years past, finds as an invariable rule that the honours lie with the boys. Of 8,172 candidates on the last July list, 4,095 were boys and 4,077 were girls. The junior boys (2,226) outnumbered the junior girls (1,305); the senior girls (2,772) outnumbered the senior boys (1,869). The age-advantage, therefore, lay decidedly with the girls. Now for the results: 919 boys (22½ per cent.) and 475 girls (11 per cent.) obtained honours; 256 boys (6¼ per cent. of the total entry) obtained first-class honours, whilst 39 girls (less than 1 per cent. of the total entry) attained that standard.

MERCHANT SHIPBUILDING SITUATION.

LORD PIRRIE, Controller General of Merchant Shipbuilding, has made a statement regarding merchant shipbuilding progress from which we make the following extracts: Considerable progress has been made with the construction of new private yards and extensions, as well as the installation of the necessary plant and labour-saving devices. New shipbuilding berths are being brought into use, on which keels are being laid, but of course another six or eight months must necessarily elapse before the completed vessels can be delivered. It is a matter of satisfaction to me to note the manner in which we are receiving the co-operation of not only organised but individual labour in connection with the use of labour-saving devices and other contributory causes of improved output. In several of the yards men who two or three months ago were opposed to pneumatic riveting are now actually applying for the pneumatic tools, and these are being supplied to them as quickly as possible.

Plant has been diverted from the National Shipyards in order to supply the immediate needs of the private shipbuilders. I have distributed amongst the private yards 45 pneumatic riveting hammers which were intended for Chepstow; a number of air compressors which were just ready for delivery to Chepstow have been diverted; and I have also supplied the private yards with a number of heavy shipyard machines, such as plate-bending machines, which were ready for the National Yards. This will not delay the work in the National Yards as you might assume, because as previously announced I have arranged for the transfer to private yards of the units constructed by the bridge-building firms for the first 11 of the fabricated ships, which were to have been laid down in the National Yards. In the meantime the constructional work at the National Yards is proceeding rapidly.

Forty-nine yards are now solely engaged on cargo-shipbuilding, and every month the number is increasing. During the last six months the tonnage of vessels "in the water"—that is, the vessels launched and fitting-out—has been brought down from 415,000 gross tons to 224,000 gross tons.

The principal reasons for the adoption of a programme of concrete ship construction towards the end of last year was the then shortage of steel and the lack of skilled men. I am still of opinion that the action of my predecessor in not overlooking this method of increasing the tonnage output was perfectly sound, but the question of further concrete construction will require very serious consideration now that it is found a larger proportion of skilled labour is required than was originally considered necessary.

There has been a very large increase in recent months in the volume of ship repairs, and as these always take precedence, and consequently draw men away from new construction, this factor should be borne in mind when considering the output of new ships alone. In fact it is only possible to obtain a correct view of the situation by taking—as I do—the total number of ships (new or repaired) put into service, but for obvious reasons it is not advisable to publish the figures for repairs. The real state of affairs in the shipping industry is revealed by the figures issued by my friend, Sir Joseph Maclay, the Shipping Controller, of the tonnage of steamships of 500 tons and over entering and clearing United Kingdom ports from and to ports overseas. His latest figures show that there has been an increase in the months' tonnage between January and July this year of 1,382,235 tons, or 22 per cent.

These figures quite confirm my view, and should satisfy the public that all the departments concerned are fully alive to the necessities of the situation—that is to say, the combined results of new merchant construction, merchant ship repairs, and the efficient operation of shipping by the Controller. This increase of 22 per cent. has been achieved notwithstanding a deficit of 594,143 gross tons during the seven months to July 31, as between the tonnage of British merchant ships produced and British merchant losses.

I have had several conferences recently with the First Lord on the question of the division of the shipbuilding effort as between naval and merchant construction. As you know, the necessity for anti-submarine craft has hitherto made such demands upon the shipbuilding resources of the country as seriously to restrict the output of merchant ships. As a result of my representations, the First Lord—who has given me every consideration and assistance—has now agreed to transfer a large number of men from naval to merchant construction, which will give a great impetus to merchant shipbuilding. I must, however, warn you that here again we cannot give immediate results, and it will be some little time before the effect of this additional labour will be reflected on the actual deliveries of merchant ships.

The question has been asked "whether the policy of organised labour is not still delaying measures of dilution in many forms which if adopted and exploited with good will would have a marked effect in increasing output." The point raised is such a fair one that I think I should endeavour to answer it. If the output of merchant ships for the six months, September 1, 1917, to February 28, 1918 (641,377 gross tons), is compared with the output for the six months, March 1, 1918, to August 31, 1918 (871,263 gross tons), it will be seen that we have produced 36 per cent. more tonnage during the second period. I have carefully examined the figures as to labour engaged during the same two periods, and I find that the increase is only 8 per cent. I think this increase of 36 per cent. in output with only 8 per cent. more labour over the last two six-monthly periods should convince the public that employers and men are now working much more satisfactorily and pleasantly together, and this also confirms the impressions I gained from the employers and men I came personally into contact with during my recent visits.

FUEL SAVING IN THE UNITED STATES.—The engineers of the United States Fuel Administration are discussing a plan of organisation in connection with conservation of fuel in power plants throughout the United States. The programme contemplated will extend into all States east of the Mississippi, and include Louisiana, Missouri and Minnesota. An administrative engineer will be appointed for each of the States in the area mentioned. This plan is the result of conferences with the Federal administrators and their committee for the group of States which together consume about 70 per cent. of all coal used in the United States, exclusive of railroads. The plan has received the endorsement of all of these States, as well as the approval by the United States Bureau of Mines and the committee of consulting engineers on conservation and publicity, which represents the engineering council of the four national engineering societies. It is believed that from 10 per cent. to 20 per cent., that is from 25,000,000 tons to 50,000,000 tons of coal per year, can be saved by better operation of steam power plants, using their present equipment, and without installation of new apparatus.

NEW QUARTZ-MERCURY LAMP.—As the ordinary quartz-mercury lamp, with its nearly horizontal tube, is not suitable for spectroscopic work, because the light intensity is not high, unless the lamp is used end on, M. Wolfke, of Zürich, has constructed a lamp the tube of which is bent to a ring or to a horseshoe, the limbs being in a vertical plane. He also crosses the ends of the limbs and fuses them into one another, so that they can both together be surrounded by a cooling vessel through which water is circulating. In experiments he found that the cooled lamp, especially when wholly immersed in water, could be run at 25 volts instead of 150 volts or 250 volts; but the construction of the tube, about which he gave no particulars when describing the lamp before the Deutsche Physikalische Gesellschaft last October, must be a difficult operation. At 220 volts and 2·7 amperes he obtained a light intensity of 3,000 Hefner candles, which is at the rate of 0·2 watts per candle; the resistance in series to the lamp was 13 ohms. The maximum intensity he realised was 5,000 Hefner candles.

NITRIC ACID FROM AMMONIA; ACETYLENE POISONING.—In the ammonia oxidation process, which is now so largely used over here as well as elsewhere, a current of ammonia and air is passed through one layer, or mostly two layers, of fine platinum gauze which are heated to 500 deg. or 600 deg. C., and the N is thus oxidised to NO. That certain impurities act as poison in such catalytic processes is well known, and it is not surprising to hear that acetylene is a poison for the ammonia oxidation. The chemist understands very well that a sooty flame will ruin his platinum crucible and wire, because the platinum and the deposited carbon form a carbide which is decomposed again. Then the platinum turns blackish and brittle, and when the gauze is not heated occasionally, as in the laboratory, but continuously for weeks, as in nitric acid manufacture, the effect may be serious. The practice is, we believe, to clean the platinum gauze with nitric acid, when in the course of weeks the yield of NO begins to drop, and to put in a new sheet of gauze when the trouble repeats; the old platinum is then returned to the supplier. Contamination of ammonia with acetylene is not rare. Calcium cyanamide is an important source of ammonium, and as this body always still contains some calcium carbide (from which it was prepared), acetylene naturally gets into the ammonia. According to experiments made by Guy B. Taylor and Julian H. Capps, of the United States Bureau of Mines, acetylene has a very deleterious effect upon the NO yield in the ammonia combustion. They prepared pure ammonia and added to it small percentages of acetylene. Their platinum gauze had 80 wires of 0·003 in. diameter to the inch. Gauzes, they noticed, are not at once fully active; they become more and more active in the course of a few days, after which with pure ammonia an NO yield of about 95 per cent. is generally reached. The addition of 0·02 per cent. of acetylene sufficed to lower that yield to 89 per cent.; with 0·1 per cent. of acetylene the yield dropped to 65 per cent., but recovered in the course of a few hours when the acetylene feed was cut off. With higher percentages of acetylene the small black spots on the platinum, noticed with small contamination, spread over the hot metal, which then looks dull red instead of bright red, and the oxidation fails altogether. Fortunately, Taylor and Capps found an easy method of purifying the ammonia. Both the ammonia and acetylene gas dissolve in water; the ammonia is driven out again by passing air through the solution, but the small percentages of acetylene and other impurities in the ammonia remain in the water.

"TESTING AIR COMPRESSORS."

TO THE EDITOR OF ENGINEERING.

SIR,—I have been interested to read the recent correspondence which has taken place in your paper on the testing of air compressors. I am, however, rather surprised to note the apparent ignorance which exists as to modern methods of measuring air. For the past ten years I have been interested in the general problem of fluid measurement and should advise any one who has to carry out tests which involve the measurement of a fluid to read a paper entitled "The Commercial Measurement of Air, Gas and Steam," published in the Proceedings of the Institution of Civil Engineers, vol. cciv, Session 1916–17, and read by John Lawrence Hodgson, with whom I have been associated. The paper embodies the results of many experiments and gives the theory of coefficients of several simple measuring devices and also illustrates and describes recorders and indicators which have such devices as their basis.

The chief difficulty standing in the way of obtaining accurate measurement of the output of a reciprocating compressor is the nature of the flow of air leaving the high-pressure cylinder, the pressure and discharge varying greatly during each revolution. Unless these variations can be damped out by a receiver or the air measured at a considerable distance along a pipe line great accuracy cannot be obtained. If the wave form of the pulsation can be determined corrections can be applied to meters designed for steady flows which render their readings within, say, ± 5 per cent. In the case of turbo blowers and centrifugal compressors the accuracy with which the discharge can be measured is equal to the accuracy with which electrical measurements can be made.

Referring to a paper by G. M. Clark, entitled "The Test of the Largest Air Compressor Constructed," published in the Journal of the South African Institution of Engineers, November, 1914, in which the test on a centrifugal compressor of rated capacity 7,000 kw. and running at 3,000 r.p.m. is described.

The compressor was direct coupled to a steam turbine. The author said: "In carrying out the tests the two principal quantities are the weight of water condensed and the weight of air compressed. Each of these quantities was measured by means of orifices and each measured twice over. The agreed method of measuring the air was by means of an orifice on the intake side of the compressor, and this was checked by measurements taken on a Venturi tube on the discharge side of the compressor. The agreement between the two was within 2 per cent., the air taken in being the greater. This is a satisfactory agreement, as there is always a certain amount of leakage from the machine at the labyrinths glands, this is especially the case as there were no readings in common to the two sets of observations, except the barometer which entered differently into each set of calculations."

I was for some time under Mr. Clark in Johannesburg and in the same station as the compressor above-mentioned we had five others, each of which was fitted on its discharge with a plate orifice connected to a simple manometer.

The readings of the manometer, together with the pressure gauge and thermometer readings figured every half-hour on the machine log sheet, and the quantity of air discharged from the compressor was read off from a simple chart.

Simultaneously the reading of the air pump discharge was read on another orifice and the comparison of the amount of air per pound of steam was thus obtained continuously. This formed a check on the blading of both the turbine and compressor runners and on several occasions faults were noticed and the machine stopped before considerable damage was done.

In the case of reciprocating compressors, the readings will not be so accurate, but for checking purposes the results after periods of running will be comparable. One case in which I have seen meters used satisfactorily was in Modderfontein, S.A., where four Bellis and Morcom compressors, of 1,000 h.p., compressing about 5,000 cub. ft. of free air per minute at a pressure of 120 lb. per inch² and discharging through a receiver on each machine into a common pipe line 16 in. diameter. A 16-in. Kent Hodgson gate meter was installed in a special building nearly 100 yards from the station, and was used to measure the output of the compressors, and state it in such units that the result was the cost of the electrical energy required to compress the air, assuming the air to be compressed by compressors having an agreed efficiency, the meter might equally well have read in weight of air.

Generally the measurement of air is carried on to a much greater extent out of England than it is in England, but during recent years it has been taken up in several cases where large quantities of air are used and when the simple methods that can be adopted for testing are more generally known great economies should result by their being used to check the working efficiencies of plants in use all over the country.

Yours truly,
N. H. HUNT.

19, Mornington-crescent, N.W. 1,
September 9, 1918.

TO THE EDITOR OF ENGINEERING.

SIR,—Your correspondent who signs himself "Interested," makes four assumptions, viz.:—

1. That the clearance volume air expands on a curve midway between the isothermal and adiabatic.
2. A clearance space of 15 per cent.
3. The final air pressure in the first-stage air cylinder.
4. That no air surging was present at the intake.

Proceeding on these assumptions, he arrives at the conclusion that the output was only 3,800 cub. ft., or 7½ per cent. less than was recorded on the test.

When he assumes that the expansion curve for the air in the clearance spaces lies between the isothermal and adiabatic, he is obviously confusing the expansion curve with the compression curve. It is true that the compression curve in most compressors does as a rule lie between the isothermal and the adiabatic, but the expansion curve, which is the one that enters into the calculation of the volumetric efficiency, is usually steeper than the adiabatic, since heat is still being extracted from the air by the water jackets during most of the expansion portion of the stroke.

The value of n in the index to the compression curve is commonly assumed to be 1.25, but for the expansion curve n may be as high as 1.6, depending on the efficiency of the jackets. Assuming this figure, and that the clearance space was 12 per cent., which I have reason to believe more nearly approximates the correct figure than 15 per cent., the calculated volumetric efficiency is 88.6 per cent., which corresponds to an output of 4,300 cub. ft. per minute. It is easy to get any result one fancies by making suitable assumptions. If more accurate results can be obtained by making simple calculations based on assumptions, why make tests at all?

Yours truly,
JOHN M. WALSHE.

38, Constance-road, Edgbaston, Birmingham,
September 10, 1918.

"COAL SAVING BY SCIENTIFIC CONTROL OF STEAM BOILER PLANTS."

TO THE EDITOR OF ENGINEERING.

SIR,—I note with interest your correspondence on fuel economy and the various suggestions made by your correspondents. As a boiler inspector I have as good an opportunity as anyone of seeing the real state of affairs. I can assure you, Sir, it is a tale of appalling waste. I see little hope of improvement until there is a general educating-up from the top to the bottom as to the importance of this question. We hear a lot about the ignorance in the firehole (but can you expect much different when the opinion is held in the office that any one can be a fireman), but what about the apathy and indifference at the head? The firehole is usually regarded as a necessary evil, to be kept away from as much as possible. No expense is spared in the works to arrive at the cost of any article, most can tell to the fraction of a penny what it costs, but when it comes to the heart of the real business, how many can say the pounds of water being evaporated per pound of coal? I don't know one! As to what instruments should be fitted depends on the size of the plant. But every steam user should be able to say the quantity of fuel used, the quantity of water evaporated as measured by meter-pounds of water evaporated per pound of fuel, and temperature of feed. The quantity of ashes should also be kept account of. From tests made in America it has been found, for every 1 per cent. of dirt in the fuel it decreases the fuel efficiency 2 per cent. From some further tests in America it is stated that no part of the boiler should be less than 42 in. from the fire bed. Of course, that distance is not possible in Lancashire or Cornish boilers, but great benefit could be found, if instead of the grate level being at the centre of the flue, it could be lowered 2 in. or 3 in. with a fall from front to back of fire grate of another 3 in. or so. I know, in one battery of boilers, that have their fire grate set lower than the others, the engineer tells me they are much the best steamers. Amongst the many defects which I come across in practice, which all make for fuel loss and which I never see mentioned, are leakage of air round boiler fronts and blow-off recess brickwork. I find this in nine out of ten boilers. Incidentally I consider the present method of fireclay and brickwork round boiler fronts could easily be improved; I know of one or two firms that have done so, with satisfactory results. Bridges are too high, flues too small, fire grate too large. No attempt is made to regulate draught by damper; it is left wide open whether it is needed or not. Flue gases are short-circuited at back end into side flues; I often find spaces here of from 1 in. to 5 in. Flues are not cleaned frequently enough; I find some actually run twelve months between each cleaning, and from four to six months is the rule. As soot is about the best non-conductor of heat you can find, you don't require a big thickness to produce a large loss. I saw it stated the other day that soot $\frac{1}{16}$ in. thick gave a loss of conductivity of 9.5 per cent. up to 69 per cent. for a thickness of $\frac{5}{8}$ in. When I tell you I often find a layer of $\frac{1}{4}$ in. to 1 in. thick, you may form some idea of the loss going on. As a suggested remedy for this state of affairs, I would suggest the following:

In each town or district a fuel inspector with sound practical sense, together with the necessary staff be appointed. Each steam user in this district should furnish once a week, or month, a brief record as to how he is using the coal, viz.: The quantity of coal used per week or month; name of colliery supplying; quantity of water actually metered; pounds of water evaporated per pound of coal; temperature of feed; quantity of ashes. Of course, many more questions could be asked, but I doubt, if you ask too many, the thing will defeat its own end. All that is required is an approximate idea as to how the fuel is being used. This inspector or his staff should make a personal visit to each steam user in his district, should see for himself the correctness of these reports furnished, and make such suggestions as he may consider necessary. He might arrange classes for the firemen in the evening, and show by simple language or by testing some boiler the best methods to promote fuel economy. Those who show they have grasped what is required should be granted a certificate which would carry with it an extra 2*s.* 6*d.* or 5*s.* for the owner, on standard rates. Those firms who make the best showing on the fuel returns should have first consideration for whatever fuel is going, and those who make a bad record should get no fuel at all till they alter their methods. If 50,000,000 tons are wasted each year, as it has been stated, and this can be saved by correct methods, putting the value of each ton at 1*l.*, the cost of running such a staff as I have outlined would not cost one-fiftieth of the total saved. In conclusion, although there is usually a large loss in the firehole, there are many engines which are in such bad order that they are gluttons for fuel, but that is another side of the question.

Yours faithfully,
A. BENNETT.

19, Monument Park, Wigan.

TO THE EDITOR OF ENGINEERING.

SIR,—In following up Mr. Brownlie's articles regarding the above, and also Mr. Casmey's no less valuable letters, which in my opinion go to the root of the enormous waste which has been going on for such a long time, there is one point, viz., the area of the opening at the bridge, on which I would very much like to have their views, and also to know if they had come to their decision through having had the bridges built at different heights and in different ways, viz., solid brick bridge, brick bridge with hot air and steel bridge with hot air. I have pleasure in thanking both Mr. Brownlie and Mr. Casmey for their valuable contributions.

Yours faithfully,
W. LINDSAY.

1, Newton-place, Glasgow, September 4, 1918.

FEDERATION OF BRITISH INDUSTRIES.—H.E. Mr. Michalocopoulos, Greek Minister of Agriculture, accompanied by eight Greek Commercial Delegates, will arrive in London on Sunday next, and will make a tour to several of our principal industrial establishments throughout the provinces. Attached to the Greek delegates are Mr. A. T. Waugh, H.B.M., Commercial Attaché at Athens; Mr. Guy Locock, C.M.G.; and Mr. E. C. D. Rawlins (lately H.M. Consul for Crete), both in the Department of Overseas Trade; and Lieutenant Lambros, R.N.V.R., attached to the same department. Officials of the Federation of British Industries attached to the tour are Vice-Admiral Sir Charles Dundas, K.C.M.G.; Mr. Edmund L. Hill, M.I.M.E., M.I.E.E.; and Mr. H. W. Babington-Browne.

TURPENTINE AND TURPENTINE SUBSTITUTE CONTROL ORDER, 1918.—The attention of the Minister of Munitions has been drawn to sales and purchases without licence of heavy distillates and various other products of petroleum capable of being used as a substitute for spirits of turpentine. All traders, manufacturers and distillers are reminded that the purchase, sale or use of such products without licence is illegal, and is subject to the penalties scheduled under the Defence of the Realm Acts and Orders thereunder. It is essential that all consumers or distributors of quantities exceeding 5 gallons per month of turpentine, white spirit, or turpentine substitute, or other products of petroleum as enumerated above, should obtain a licence to purchase under the said order from the Controller, Mineral Oil Production Department, St. James' Park, S.W. 1.

THE SOUTH AFRICAN RAILWAYS.—Ever since the first railway was built in South Africa enormous orders have been placed in Great Britain for locomotives and rolling-stock, says *The British and South African Export Gazette*. Since the Union, many of the purchases made by the South African Railways and Harbours Administration have gone out complete; others in a form which lent itself to easy erection in the railway sheds at Pretoria, Salt River or Uitenhage. The Administration would have been a customer on a much wider scale than at any previous period but for the war, for expansion in the production of foodstuffs, and the development of the coal industry has been so great that enormous additions to the rolling-stock became imperative, the orders for most of which would undoubtedly have been placed in this country had manufacture and export been possible. The following new engines and rolling-stock were still on order or authorised on October 31 last: Engines, 143; engine tenders, 24; coaching stock, 238; wagon stock, 2,471. These orders sufficiently show that the Administration was fully alive to the extent of the demands likely to be made upon the railways, and did its utmost to provide against them; but unfortunately deliveries have been on a disappointing and altogether inadequate scale. Valuable orders were placed in England in the early days of the war, and many of them, probably the majority, still remain unexecuted. Almost in despair, the Department placed orders for 38 new locomotives in the United States of America, and hoped for delivery by the end of June. Our contemporary is not aware that any of these have yet been landed in South Africa, and with America's growing demands for transport for purely war material, it is extremely improbable that many of the locomotives, if indeed any, will be in service this year. That the Administration will make every effort to meet traffic requirements goes without saying, but it is likely to find itself in a very awkward position with largely increased quantities of coal, foodstuffs, wool and hides to handle. British locomotive and rolling-stock builders have the satisfaction of knowing that the requirements of the South African Railways will remain long after the war has finished, for peace will bring an unexampled demand by the whole world for those necessities of life and raw materials which South Africa can furnish. These, and the extensions contemplated, will all require railway transport on a vast scale, and it is safe to say that the lines will be working to their fullest capacity for many years to come.

THE 300-H.P. MAYBACH AERO-ENGINE.

(Concluded from Page 287.)

Petrol Pump.—The design of the compound petrol pump is shown in the sectional drawing, Fig. 40, and also in the sectional perspective sketch, Fig. 41. The pump consists of two opposed cylinders, in which a reciprocating plunger works, the ends of which operate as single acting pumps. The pump plunger carries a yoke fitted with a sliding bush, which forms the crank-pin bearing of the small pump crankshaft, driven, as already described, off the rear end of the oil pump spindle at half engine speed. The bore of the petrol pump plunger is 15 mm. and the stroke is 17 mm. The outer ends of the pump barrels are as shown, and are fitted with screwed plugs, which form compression chambers.

The small non-return suction valves are situated directly above and below the two compression chambers, and the two petrol delivery valves are fitted above the compression chambers. The valves communicate with the compression chambers through small ports drilled in the pump barrel. Both the suction and delivery valves are of the poppet type, and each delivery valve is spring loaded by means of a small brass wire coil spring. The valves are supported in guides drilled in the unions which form the valve boxes, and to which the petrol delivery pipes from the petrol tanks and to the carburettors are connected. The internal diameter of both these pipes is 10 mm. It will be noticed that both the suction valves are fed by the same petrol supply pipe as shown in the sketch.

The centre portion of the petrol pump body, which is a gun-metal casting, forms a small circular crank chamber for the pump plunger, and is fitted at the bottom with a detachable cover plate, which is secured by six set screws. The whole of the pump crank chamber is filled with oil under pressure from the main lubrication system, through an oil pipe connected to the centre of the pump body casting, and leading from the rear end of the detachable main oil lead pipe on the engine. By this means the efficient lubrication of the yoke and sliding bush and also of the seating of the pump plunger is assured.

R.A.E. Tests of Petrol Pump.—Flow tests at three speeds with varying heads were taken; in order to represent working conditions in the engine, flow tests were also taken through jets similar to those employed on the engine.

Delivery Tests.—The petrol pump was run at three speeds, viz.: 550, 800, and 1,275 r.p.m., and the outlet pipe was connected to the pump against a variable head from zero to 6 lbs. per square inch. The maximum and minimum petrol delivery at these speeds and heads are given in the following table:—

Revs. per min.	Maximum flow. Zero head.	Minimum flow. 6 lbs. head.
550	300 pints per hour	167 pints per hour
800	422 pints per hour	264 pints per hour
1,275	630 pints per hour	498 pints per hour

Fig. 42 shows the graphs of these tests with varying heads plotted against delivery at constant speeds. These curves are quite normal, and it is evident from them that the valves are acting well, and that the drop in delivery with increasing head resistance is due to cavitation. The pressure of the oil in the pump case during these tests varied between 15 and 20 lbs. per square inch, and the leakage of oil and petrol past the end bearing of the pump spindle during one hour's run was approximately one pint.

Tests through Engine Delivery Jets.—In the engine the petrol is delivered through restricting jets (Fig. 34, page 256 *ante*) into the constant-level tanks, which feed the jet chambers below, and are provided with overflows to the main petrol tank. In the tests both outlets of the pump were connected by a Y piece with one delivery pipe, the end of which was closed by a plate $\frac{1}{16}$ in. in thickness, having two 0.07 in. diameter jet holes drilled through. The petrol pump was run at the three speeds as in the former tests, and the following results recorded of delivery and head resistance:—

R.P.M.	Head resistance.	Pints per hour.
550	4.5 lbs.	160 pints
800	9 lbs.	218 pints
1,275	25 lbs.	360 pints

Starting Gear.—The principle of the Maybach starting gear is now so well known that only a brief description of the mechanism and a few details of the construction will be necessary. In the semi-diagrammatic cross-sectional drawing of the engine, Fig. 42, the working principles of this simple and distinctive starting mechanism are clearly shown. By the depression of the hand lever A on the induction side of the engine, all the tappets are lifted off their cams through the action of small lugs formed on the top of the tappets, which fit into slots cut in the tubular lay shafts BB. All the valves, both inlet and exhaust, are thus opened in the cylinder heads; and at the same time the hand lever A closes the shutter C in the exhaust manifold by the connection of levers shown in the drawing. The valves and exhaust shutter are then locked in this position by a peg, which is inserted in two holes D, which now coincide in the hand lever A. By the action of a large hand suction pump E in the pilot's seat, gas is then drawn into the combustion chambers through the inlet valves and induction pipe from the carburettors as indicated in the diagram. When the cylinders are charged the valves are returned to their normal positions by the withdrawal of the locking pin in the hand lever A, and simultaneously the free passage in the exhaust manifold is again opened by the shutter C. Ignition is then effected by means of a Bosch hand-starter magneto in the pilot's seat. It will be noticed that the exhaust shutter lever is provided with a spring-loaded tie rod to ensure a true seating for the shutter. In order to prevent the engine from being started until the hand lever has been released to its off position, the locking hole in the lever which takes the pin is made in such a way that only a special form of locking pin can be used. For this purpose the handle of the starting magneto is made easily detachable, and is used for the purpose of locking the hand lever A. It is thus practically impossible to cause ignition with the valves open and the exhaust passage closed, which, of course, would cause firing back into the carburettors, and probably also result in destroying the hand pump.

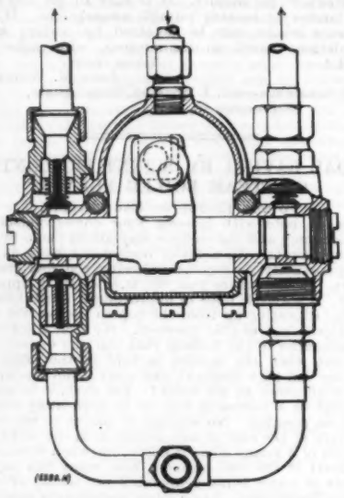

FIG. 40. SECTIONAL ARRANGEMENT OF PETROL PUMP.

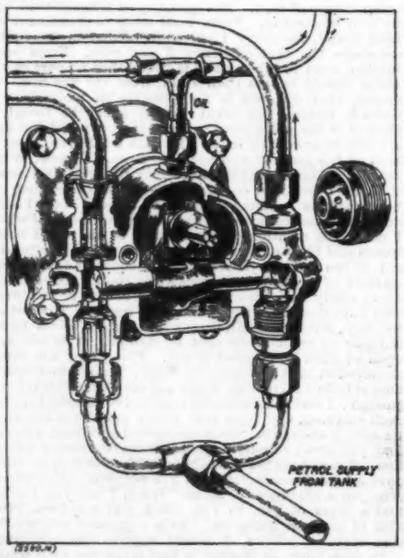

FIG. 41. SECTIONAL SKETCH OF PETROL PUMP.

ENGINE TEST REPORT AT R.A.E. 5.4.18.

Calibration and Endurance Tests.—The Maybach engine (No. 1261), after several slight repairs had been carried out to the cylinders and propeller hub flange and coupling, was erected on a test bed, coupled to a Heenan and Froude dynamometer, and submitted to the following power and consumption tests, including a one hour's duration test at normal speed. The results of the calibration tests are as follows:—

R.P.M.	1,200	1,300	1,400	1,500
B.H.P.	258	279	294.5	304.5
Brake, M.E.P. ...	120.5	120.3	118	113.9
Petrol consumption in pints /B.H.P. hour	.53	.52	.526	.545

The results of these tests are shown graphically on the diagram (Fig. 43).

One Hour Test.—At the conclusion of the above tests a run of one hour's duration at normal revolutions (1,400 r.p.m.) was carried out with the following results:—

Average B.H.P.	290.
Petrol consumption	20 gallons = .55 pints per B.H.P. hour.
Oil consumption	11 pints = .038 pints per B.H.P. hour.
Oil pressure	5 lbs./sq. in.
Oil temperature	67°C.
Water temperature (inlet) ...	57°C.
Water temperature (outlet)...	68°C.

Valve Timing during Tests.

Inlet.	Exhaust.
O. 8°E.	O. 33°E.
C. 35°L.	C. 7°L.
Magneto advance	38°E.

Running was steady at all speeds between 900 and 1,400 r.p.m., but owing to the fact that the propeller hub flange on the crankshaft was damaged, and was running slightly out of truth, the vibration became excessive above 1,400 r.p.m. Considerable trouble was experienced with the water connection between the cylinders on the exhaust side. The running became unsteady below 900 r.p.m.

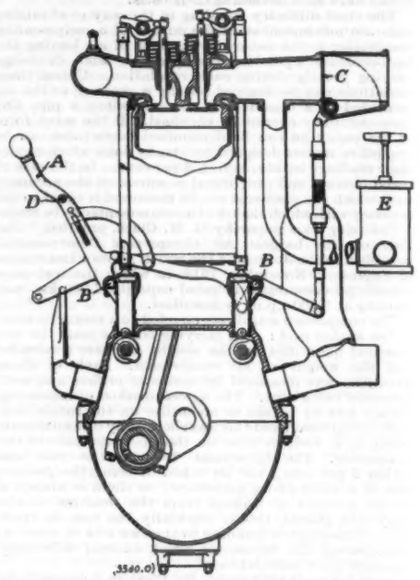

FIG. 42. DIAGRAMMATIC SECTION OF ENGINE SHOWING FUNCTIONS OF STARTING MECHANISM.

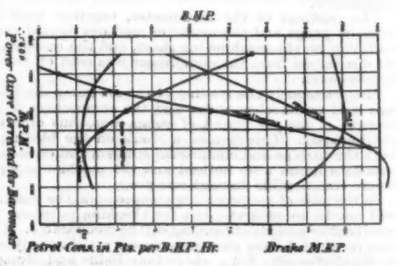

FIG. 43. CALIBRATION CURVES; R.A.E. TESTS.

Distribution.—Owing to the exhaust manifold being fitted as part of the engine starting gear, it was not possible to form an idea of the distribution. A diagram of the inlet and exhaust valve life is shown graphically in Fig. 20, page 253 *ante*.

F. G. C. Ap.D. (L.).
May, 1918.

J. G. WEIR,
Lieut.-Colonel, Controller,
Technical Department.

GENERAL DATA.

Make of engine and rated H.P.	Maybach 300 h.p.
Type number	1,261.
Number and arrangement of cylinders	Six vertical.
Bore	165·0 mm. = 6·50 in.
Stroke	180·0 mm. = 7·09 in.
Stroke/Bore ratio	1·09 : 1.
Area of one piston	213·825 sq. cm. = 33·2 sq. in.
Total piston area of engine ..	1282·95 sq. cm. = 199·2 sq. in.
Swept volume of one cylinder ..	3848·85 cu. cm. = 235·3 cu. in.
Total swept volume of engine ..	23098·1 cu. cm. = 14120·0 cu. in.
Clearance volume of one cylinder.	776·9 cu. cm. = 47·64 cu. in.
Compression ratio	5·95 : 1.
Normal B.H.P. and speed ..	294·0 b.h.p. at 1,400 r.p.m.
Maximum B.H.P. and speed ..	304·5 b.h.p. at 1,500 r.p.m.
Normal B.M.E.P. ..	117·7 lbs. per sq. in at 1,400 r.p.m.

METALLURGICAL ANALYSIS OF PRINCIPAL PARTS.

	Carbon.	Graphite Carbon.	Combined Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Nickel.	Chromium.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Cylinder head	—	2·57	0·91	1·60	0·70	0·131	0·34	—	—
Cylinder barrel	0·49	—	—	0·33	1·01	0·028	0·054	—	—
Cylinder water jacket	0·25	—	—	0·27	0·63	0·032	0·037	—	—
Piston	—	2·42	0·83	1·29	0·83	0·111	0·30	—	—
Gudgeon pin floating bush	—	2·39	0·65	1·43	0·76	0·146	0·47	—	—
Gudgeon pin	0·28	—	—	0·23	0·48	0·028	0·022	—	—
Connecting-rod	0·15	—	—	0·33	0·31	0·027	1·010	1·42	0·49
Inlet valve	0·53	—	—	0·30	0·48	0·052	0·044	4·01	0·51
Exhaust valve	0·10	—	—	0·20	0·26	0·019	0·023	3·62	1·16
Crankshaft	0·31	—	—	0·31	0·63	0·030	0·015	4·01	0·83
Camshaft	0·40	—	—	0·25	0·23	0·022	0·040	3·46	0·68
Camcore	0·17	—	—	0·23	0·75	0·036	0·014	0·47	—

	Lead.	Iron.	Tin.	Copper.	Zinc.	Antimony.	Silicon.	Manganese.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Big-end bearing metal	3·51	—	80·05	6·34	—	9·90	—	—
Main journal bearing	0·92	—	77·65	10·00	—	11·18	—	—
Crankcase	—	0·99	—	0·87	12·01	Aluminium (by Diff) 86·57	0·56	Trace.

MECHANICAL TESTS.

Mechanical tests were made on the crankcase and crankshaft, the results of which are given below :

Crankcase.

Mark.	Diameter.	Maximum Stress.	Elongation, per Cent.
T	0·253	11·65	1
L	0·254	11·28	1

Crankshaft.

Position.	Mark.	Diameter.	Yield Stress.	Maximum Stress.	Per cent. Elongation on 4A.	R. of A.	Impact.
		in.	Tons/sq. in.	Tons/sq. in.		Per cent.	Ft.-lbs.
End	1	0·254	50·0	63·1	14·3	56·3	17·21
Journal	2	0·254	—	—	—	—	—
Web	3	0·254	61·6	64·1	15·1	54·6	16·121
Long.	4	—	—	—	—	—	—
Crankpin, long	5	0·254	63·6	67·1	15·1	55·7	12·12
	6	—	—	—	—	—	—
Web, trans.	7	0·254	61·4	65·3	7·2	10·5	5·5

Maximum B.M.E.P.	120·5 lbs. per sq. in. at 1,200 r.p.m.
Piston speed	1654.0 ft. per min. at 1,400 r.p.m.
Mechanical efficiency (calculated)	86·0 per cent.
Indicated mean pressure (calculated)	137·0 lbs. sq. in.
Fuel consumption per B.H.P. hour.	0·526 pint = 0·473 lbs.
Brake thermal efficiency	23·9 per cent.
Indicated thermal efficiency	33·6 per cent.
Air standard efficiency	51·0 per cent.
Relative efficiency	65·9 per cent.
Cu. in. of swept volume per B.H.P.	4·80 cu. in.
Sq. in of piston area per B.H.P.	0·678 sq. in.
H.P. per cu. ft. of swept volume	360·0 b.h.p.
H.P. per sq. ft. of piston area	212·4 b.h.p.
Direction of rotation of crankshaft	Anti-clockwise (facing propeller).
Direction of rotation of propeller	Anti-clockwise (facing propeller).
Type of valve gear	Overhead valve rockers and push rods.
Type of starting gear	Maybach of special design.
Number of carburettors	Two Maybach.
Bore of main jets	Variable from 0·0 to 2·5 mm.
Bore of pilot jets	Variable from 0·0 to 1·1 mm.
Fuel consumption per hour	19·33 gallons.

Valve Areas and Gas Velocities.

Diameters—	
Induction pipe	62·0 mm. = 2·44 in.
Inlet port	45×67 mm. = 1·77×2·64 in.
Exhaust port	45×67 mm. = 1·77×2·64 in.
Exhaust branch pipes	66·0 mm. = 2·60 in. (approx.).
Cross Sectional Areas.	
Induction pipe	29·26 sq. cm. = 4.57 sq. in.
Inlet port	30·15 sq. cm. = 4·67 sq. in.
Inlet valve (⌀ dh.)	4·416 sq. in. (total).
Exhaust valve (⌀ dh.)	4·366 sq. in. (total).
Exhaust port	30·15 sq. cm. = 4·67 sq. in.
Exhaust branch pipes	34·11 sq. cm. = 5·31 sq. in.
Gas Velocities.	
Induction pipe	196·1 ft. per sec.
Inlet port	196·1 ft. per sec.
Inlet valve	208·0 ft. per sec.
Exhaust valve	210·0 ft. per sec.
Exhaust port	196·1 ft. per sec.
Exhaust branch pipes	172·5 ft. per sec.

Inlet Valves (Two per Cylinder).

Outside diameter	54·0 mm. = 2·126 in.
Port diameter (in cylinder head)	48·0 mm = 1·89 in.
Width of seating	3·5 mm. = 0.137 in.
Angle of seating	30°
Radius under valve head	20·0 mm. = 0·787 in.
Lift of valve	9·45 mm. = 0.372 in.
Diameter of stem	11.0 mm. = 0·433 in.
Over-all length of valve	136·5 mm. = 5·373 in.
Number of springs per valve	One.
Free length of spring	52·5 mm. = 2.066 in.
Length of spring in position (no lift)	39·5 mm. = 1·55 in.
Mean diameter of coils	51·0 mm. = 2.00 in.
Gauge of wire	No. 6 B.W.G.
Ratio length of spring/lift of valve	4·17 : 1.
Weight of valve complete with spring	0·843 lb.
Weight of spring bare	0·281 lb.
Inlet valve opens, deg. on crank	8° early.
Inlet valve closes, deg. on crank	35° late.
Period of induction	223°
Inlet tappet clearance	0·3 mm. = 0·012 in.

Exhaust Valves (Two per Cylinder).

Outside diameter	54·0 mm. = 2·126 in.
Port diameter (in cylinder head)	48·0 mm. = 1·89 in.
Width of seating	3·5 mm. = 0.137 in.
Angle of seating	30°
Radius under valve head	9·0 mm. = 0·354 in.
Lift of valve	9·34 mm. = 0·368 in.
Diameter of stem	11·0 mm. = 0.433 in.
Length of valve guide	80·0 mm. = 3·140 in.
Over-all length of valve	152·5 mm = 6·00 in.
Number of springs per valve	One.
Free length of spring	52·5 mm. = 2·06 in.
Length of spring in position (no lift)	39·5 mm. = 1·55 in.
Mean diameter of coils	51·0 mm. = 2·00 in.
Gauge of wire	No. 6 B.W.G.
Ratio. Length of spring/lift of valve	4·21 : 1.
Weight of valve complete with spring	0·881 lb.
Weight of spring bare	0·281 lb.
Exhaust valve opens, deg. on crank	33° early.
Exhaust valve closes, deg. on crank	7° late.
Period of exhaust	220°
Exhaust tappet clearance	0·4 mm.

Inertia Forces, Bearing Loads, Etc.

Weight of piston, complete with rings and gudgeon pin	14·05 lbs.
Weight per sq. in. of piston area	4235 lbs.
Weight of connecting rod complete	8·93 lbs.
Weight reciprocating part of connecting rod	3·305 lbs.
Total reciprocating weight per cylinder	17·355 lbs.
Weight per sq. in. piston area	0.538 lb.
Length of connecting rod (centres)	310·0 mm. = 12·20 in.
Ratio. Connecting rod/crank throw	3·445 : 1.
Inertia, lbs. sq. in. piston area, top centre	137·0 lbs. sq. in.
Inertia, lbs, sq. in. piston area, bottom centre	75·5 lbs. sq. in.
Inertia, lbs. sq. in. piston area, mean	53·25 lbs. sq. in.
Weight of rotating mass of connecting rod	5·625 lbs.
Total centrifugal pressure	1106 lbs.
Centrifugal pressure, lbs. sq. in. piston area	34·4 lbs. sq. in.
Mean average fluid pressure, including compression	48·0 lbs. sq. in.
Mean average loading on crank-pinbearing total from all source in terms of lbs. sq. in. piston area	118·0 lbs. sq. in.
Diameter of crank-pin	66·0 mm. = 2·598 in.
Rubbing velocity	15·85 ft. sec.
Effective projected area of big end bearing	43·23 sq. cm. = 6·70 sq. in.
Ratio. Piston area/protected area of beg end bearing	4·96 : 1.
Mean average loading on big end bearing	585 lbs. sq. in.
Load factor on big end bearing	9270 lbs. ft. sec.

Cylinders.

Over-all height of bare cylinder from top of base chamber	479·5 mm. = 18·87 in.
Depth of spigot at base of cylinder	3·5 mm. = 0·13 in.
Diameter of cylinder over water jacket	185·0 mm. = 7·28 in.
Valve centres (between inlet and exhaust)	63·0 mm. = 2·48 in.
Thickness of flange at base of cylinders	12·0 mm. = 0.47.
Number of holding-down studs per cylinder	Four.
Diameter of holding-down studs	19·0 mm. = 0.74 in.
Thickness of water jacket	1·0 mm. = 0·039 in.
Mean thickness of combustion chamber wall	8·0 mm. = 0·31 in.
Mean thickness of cylinder barrel	3·0 mm. = 0·11 in.
Tensile stress	6640 lbs. sq. in. (approx.) (Assumed maximum pressure 450 lbs. sq. in.)

Piston.

Type of piston	Cast-iron (flat crown)
Diameter at top	164·25 mm. = 6·466 in.
Diameter at bottom	164·75 mm. = 6·486 in.
Length	511·00 mm. = 5·044 in.
Ratio. Piston length/cylinder bore	·914 : 1.
Number of rings per piston	Three piston rings, one scraper ring.
Position of rings	All above gudgeon pin.
Width of rings	6·5 mm. = 0·255 in.
Gap of rings in cylinder	1·39 mm. = 0.055 in.

Connecting Rod.

Length between centres	310·0 mm. = 12·205 in.
Ratio. Connecting rod/crank throw.	3·44 : 1.
Little end bearing type	Floating cast-iron bush.
Floating bush, diameter, inside	38·0 mm. = 1·496 in.
Floating bush, diameter, outside	44·3 mm. = 1·743 in.
Floating bush, effective length inside.	93·0 mm. = 3·661 in.
Floating bush, projected area of bearing on gudgeon pin	35·35 sq. cm. = 5.48 sq. in.
Ratio. Piston area/projected area of little end bearing	6·06 : 1.
Big end bearing. Type	Bronze shelllined white metal
Big end bearing. Diameter	66·0 mm. = 2·598 in.
Big end bearing. Length (actual)	73·56 mm. = 2·893 in.
Big end bearing. Projected area	43·23 sq. cm. = 6·700 sq. in.
Ratio. Piston area/projected area of big end bearing	4·96 : 1.
Number of big end bolts	Four.
Full diameter of bolts	14·0 mm. = 0.551 in.
Diameter at bottom of threads	12·0 mm. = 0·472 in.
Total cross sectional area, bottom of threads	4·520 sq. cm. = 0·70 sq. in.
Pitch of threads	1·5 mm.
Total load on bolts at 1,400 r.p.m.	5,824 lbs.
Total load on bolts at 1,600 r.p.m.	7,502 lbs.
Stress per sq. in. at 1,400 r.p.m.	8,320 lbs. sq. in.
Stress per sq. in at 1,600 r.p.m.	10,860 lbs. sq. in.

Crankshaft.

Number and type of main bearings	Seven bronze shelllined white metal.
Cylinder centres	187·0 mm. = 7·362 in.
Crank-pins.	
Outside diameter	66·0 mm. = 2·598 in.
Inside diameter	38·0 mm. = 1·496 in.
Length	74·0 mm. = 2·913 in.
Journals.	
Outside diameter	66·0 mm. = 2.598 in.
Inside diameter	36·0 mm. = 1·417 in.
Length, propeller end	67·0 mm. = 2·638 in.
Length, rear end	67·0 mm. = 2·638 in.
Length, centre	67·0 mm. = 2·638 in.
Length, intermediate	67·0 mm. = 2·638 in.
Crank Webs.	
Width	95·0 mm. = 3·740 in.
Thickness	23·0 mm. = 0.906 in.
Radius at ends of journals and crank-pins	4·5 mm. = 0·171 in.
Weight of complete shaft	99·0 lbs.

Working Clearances.

Piston clearance, top (total)	0·75 mm. = 0·029 in.
Piston, clearance, bottom (total)	0·25 mm. = 0·009 in.
Side clearance of connecting rod in piston (total)	11·8 mm. = 0·464 in.
Side clearance of big end on crank-pin (total)	·44 mm. = ·0173 in.
End clearance of crankshaft in main bearings	3·0 mm. = 0·118 in.
Clearance of valve stem in guide (inlet)	0·12 mm. = ·00472 in.
Clearance of valve stem in guide (exhaust)	0·15 mm. = ·0059 in.

Lubrication System.

Number and type of oil pumps	Three, rotary gear.
Oil consumption per hour	11·0 pints
Oil consumption per B.H.P. hour	0·037 pints.
Oil temperature	65 deg. Cent..
Oil pressure	5·0 lbs. per sq. in.
Specific gravity of oil	0.899 s.p.g.
Ratio. Pump speed/crankshaft speed	1 : 2.
Pump delivery (calculated at 100 per cent. volumetric efficiency)	91 gallons per hour at normal engine revs.

Ignition.

Number and type of magnetos	Two Bosch.
Firing sequence of engine	1-5-3-6-2-4.
Ignition timing (fully advanced)	38 deg. early.
Number of plugs per cylinder	Two.
Type of plugs	Bosch 3 point.
Ratio. Magneto speed/engine speed.	1·5 : 1.

Cooling System.

Number and type of water pumps	One centrifugal.
Diameter of inlet pipe	54·0 mm. = 2·126 in.
Diameter of outlet pipe	50·0 mm. = 1·966 in.
Diameter of rotor	111·0 mm. = 4·46 in.
Water capacity of one cylinder	1284·0 cub. cm.
Number and type of radiators	One, semi-circular honeycomb.
Ratio. Water pump speed/engine speed.	2 : 1
Water temperature, inlet	57 deg. C.
Water temperature, outlet	68 deg. C.

Petrol Pump.

Number and type of petrol pumps	One Maybach, double acting.
Bore	15·0 mm. = 0·59 in.

Stroke	17 mm. = 0·66 in.
Normal delivery	264 pints per hour at 800 r.p.m.
Maximum delivery	630 pints per hour at 1,275 r.p.m.
Ratio. Pump speed/crankshaft speed.	1 : 2.

Weights.

Weight of complete engine, dry, with propeller boss and exhaust manifold.	911 lbs.
Weight per B.H.P., ditto ..	3.10 lbs.
Weight of fuel per hour ..	139 lbs.
Weight of oil per hour (s.p.g. ·899)	12·36 lbs.
Total weight of fuel and oil per hour.	151·36 lbs.
Gross weight of engine in running order, less fuel and oil (cooling system at ·65 lbs. per B.H.P.).	1102·0 lbs.
Weight per B.H.P., ditto ..	3·79 lbs.
Gross weight of engine in running order, with fuel and oil for six hours (tankage at 10 per cent. weight of fuel and oil).	2100·9 lbs.
Weight per B.H.P., ditto ..	7·14 lbs.

GENERAL ANALYSIS OF WEIGHTS.

Description of Part.	No. per Set.	Average Unit in Lbs.	Weight of Complete Set in Lbs.	Percentage of Total Weight.
Cylinders, bare	6	32·75	196·50	21·59
Pistons, complete with rings and gudgeon pin set screws	6	12·30	73·80	8·11
Gudgeon pins	6	1·75	10·50	1·15
Connecting rods and floating bushes	6	8·93	49·12	5·39
Crankshaft, complete with oilrings	1	99·00	99·00	10·98
Crankshaft, complete with oil pin	1	4·00	4·00	0·44
Inlet valves	12	0·43	5·25	0·57
Exhaust valves	12	0·47	5·70	0·62
Inlet and exhaust valve springs ..	24	0·28	6·74	0·74
Inlet and exhaust valve collars, with cotters and locking device	24	0·12	3·00	0·32
Thrust, complete with ball races, propeller hub flange, and camshaft driving sprocket ..	1	17·68	17·68	1·94
Camshafts	2	10·00	20·00	2·20
Overhead valve rockers, complete	12	1·08	12·99	1·42
Overhead rocker bearings, complete	24	0·42	10·50	1·15
Valve tappets and guides	12	0·93	11·25	1·23
Crankcase, top half	1	94·30	94·30	10·36
Crankcase, bottom half	1	41·32	41·32	4·54
Bearing caps	6	2·68	16·12	1·77
Front bearing cap	1	5·56	5·56	0·61
Crankcase holding-down bolts, with clamps, nuts and washers	14	2·40	33·60	3·70
Induction pipe, complete ..	1	9·09	9·09	1·00
Propeller hub, with bolts and nuts	1	21·00	21·00	2·30
Inlet valve push rods	6	0·48	2·90	0·32
Exhaust valve push rods	6	0·49	2·97	0·33
Inlet and exhaust stiffening plates	2	2·00	4·00	0·44
Oil pumps, with drive and pipe ..	1	9·00	9·00	0·98
Rear cover plate	1	6·06	6·06	0·66
Front cover plate	1	4·00	4·00	0·44
Water pump, complete	1	8·50	8·50	0·93
Camshaft, oil and water pumps driving gears	1	13·65	13·65	1·50
Wireless clutch	1	5·06	5·06	0·55
Revolution counter gear	1	2·62	2·62	0·28
Machine gun interrupter gear ..	1	1·82	1·82	0·28
Petrol pump	1	3·50	3·50	0·38
Magnetos	2	10·75	21·50	2·36
Magneto wiring	1	4·75	4·75	0·52
Oil pipes	1	4·00	4·00	0·44
Self-starter gear	1	6·00	6·00	0·66
Exhaust manifold	1	27·00	27·00	2·96
Carburettors	2	16·00	32·00	3·51
Miscellaneous	..	..	3·75	0·41
Total weight of engine	..	..	911·00	100·00

THE METALLOGRAPHY OF TUNGSTEN.*

By ZAY JEFFRIES,† B.S., Met. E., Cleveland, Ohio.

(*Concluded from page 275.*)

Notes on Polishing, Mounting and Etching Tungsten.

Tungsten is not an easy metal to polish. It is so resistant to the action of abrasion of the polishing powders that levigated alumina can be substituted for tripoli to advantage just preceding the rouge.

White cast-iron has been used to advantage as a mounting material for small pieces of tungsten which cannot conveniently be handled without some sort of a mounting. The piece of tungsten to be mounted is put in a mould and the molten cast-iron poured around it. The white cast-iron and tungsten are so nearly the same hardness that flat surfaces can be produced on the tungsten during polishing. It is sometimes very difficult to mount and polish the smallest tungsten wires. This has been accomplished in a successful manner, however, on wires less than 0·001 in. in diameter. One satisfactory method is as follows: An ordinary malleable iron ¼-in. (9·5-mm.) pipe cap is planed on the closed end outside. It is then drilled on the inside to a plane parallel to the outside plane. A round cover glass is put on the inside of the pipe cap, on which are placed several pieces of the small tungsten wire to be polished. Another cover glass is placed on top of these wires, after which the opening of the pipe cap is filled with powdered glass. It is then put in a furnace, being maintained in an upright position, and heated for about 5 minutes to a temperature of 800 deg. to 900 deg. C. It has been found in many experiments that this temperature does not affect the structure of tungsten wire. The pipe cap with contents is then removed from the furnace and the glass which has congealed is pressed tightly into the pipe cap and allowed to cool slowly. The metal portion on the end of the pipe cap is then turned off in a lathe and the glass is exposed. This glass containing the samples of tungsten is polished in the ordinary manner until the tungsten wires are exposed, and the polishing is completed in the ordinary manner.

Boiling hydrogen peroxide is used for etching most of the tungsten products. Tungsten may also be etched electrolytically with good results, using a solution of sodium hydrate for electrolyte.

Why is Fibrous Tungsten Ductile?

This question has been the subject of much work and much thought. The fact that fibrous tungsten is ductile has been known for ten years, but no explanation has been forthcoming. The result could not have been predicted from metallurgical knowledge. The explanation has been worked out step by step. The researches which have finally resulted in an explanation also permit the postulation of some new metallographic laws relating to all metals. In making the explanation, the amorphous theory is considered valid. The explanation, however, does not depend upon the validity of the amorphous theory or any other theory; it depends on facts which have been experimentally ascertained. These researches may, in fact, be used to strengthen the amorphous theory.

Crystalline tungsten is somewhat malleable and ductile at room temperature—that is, if a single grain of tungsten can be isolated, it can be slightly deformed cold before rupturing. The cold deformation strain hardens the tungsten grain and makes it brittle, similar to this action in common ductile metals. Crystalline tungsten can also be deformed above room temperature; it is capable of more permanent deformation without becoming brittle, the higher the temperature at which the deformation is produced.

Amorphous tungsten is very brittle at room temperature. It is capable of being deformed without rupture at high temperature. Tungsten composed of small equiaxed grains is not ductile or malleable at room temperature. It may be both malleable and ductile at elevated temperatures. A fracture at room temperature shows that the break has taken place largely at the grain boundaries. Occasionally, along the fracture line, a grain is encountered which has been broken in two, but this will be caused by a local high resistance to rupture along the grain boundaries. Fine-grained tungsten can be deformed under suitable conditions (such as are outlined previously) at high temperatures.

The reasons for fibrous tungsten being ductile cold can be stated briefly as follows: Tungsten composed of equiaxed grains is brittle at room temperature because the brittle amorphous phase at the grain boundaries permits rupture before a load sufficient to deform the malleable crystalline phase can be applied. Tungsten possessing this structure is brittle even though the crystalline material present is more capable of permanent deformation at room temperature than the crystalline portions of fibrous tungsten. Fibrous tungsten is ductile at room temperature (assuming that the fibre has been produced under proper conditions) in spite of the fact that it contains more of the amorphous phase than equiaxed tungsten. It is ductile because the grain distortion by working arranges the grain boundaries in such a manner that the resistance to rupture along them is so great that rupture is forced to take place through the deformed grains themselves. These grains, which will usually have been deformed above room temperature, will possess the ability to be further deformed at room temperature; rupture through them cannot take place without further deforming them, so the metal assumes ductility. The subject of deformation of metallic grains at a certain temperature and the increase of ductility by lowering the temperature will be treated later.

We must accept as a fact, which I have observed many times, that rupture along the amorphous planes in tungsten is much more pronounced along grain boundaries than along the amorphous slip planes in deformed tungsten grains. It is probable that the path of rupture along the amorphous slip planes in a deformed grain would be many times more intricate, involving interweavings of submicroscopic size, than the path of rupture along the grain boundaries themselves. Whatever may be the explanation for this, we must accept it as fact. It should be kept in mind that only when the amorphous phase of the metal becomes very brittle does the fracture seek the grain boundaries. This condition obtains in tungsten at room temperature but not in the ordinary ductile metals.

Even a fibrous tungsten wire which is ductile is only malleable when the deforming pressure is applied at all points of its circumference at the same time, like the swaging die action. When one of these wires is placed on an anvil and struck with a hammer, it splits into many threads—that is, the deformed grains separate from each other.

Probably one of the major causes for rupture along the amorphous grain boundaries in tungsten, in preference to through the grains themselves, is the difference in coefficient of expansion of the amorphous and crystalline phases. Glass, a completely amorphous substance, can be cracked by unequal heating or cooling, the cracks resulting from the different degrees of expansion or contraction of different parts of the piece. If we consider that fine-grained tungsten is made up of crystalline grains surrounded by films of amorphous tungsten, then these two phases will have different coefficients of thermal expansion. At the higher temperatures, these differences are easily adjusted because of the plasticity of the amorphous phase. At lower temperatures, however, both the amorphous and crystalline phases will be very rigid. This will force the strains of unequal expansion during heating or unequal contraction during cooling, into either the crystalline or amorphous material, or both. There are several reasons why these strains at low temperatures should be taken up largely by the amorphous phase. The amorphous phase is the only one possessing continuity. The crystalline phase consists of grains none of which actually touch each other. The continuity of the system depends on the amorphous phase. Any difference in coefficient of expansion between the amorphous and crystalline phases, no matter in what direction the difference may be, must affect therefore the amorphous phase. If internal strains are set up in this manner at the grain boundaries, smaller external loads will be required to cause rupture than would be indicated by the actual measure of cohesion of the isolated amorphous phase.

To obtain a somewhat better idea of these phenomena, let us consider the properties of tungsten wires about 0·007 in. (0·18 mm.) diameter with four types of structure.

1. *The Whole of the Wire is Composed of a Single Grain.*—Since crystalline tungsten is somewhat malleable and ductile at room temperature, such a wire could be deformed cold. Cold deformation would strain-harden the tungsten and make it more brittle, and when continued far enough would break it because of the brittleness. The permanent deformation of the crystalline tungsten would generate amorphous tungsten at the planes of slip. The hardening and embrittling would be caused by the amorphous metal.

2. *The Tungsten Wire is Composed of Small Equiaxed Grains.*—Such a tungsten wire is brittle and fragile at room temperature. It cannot be appreciably bent (except the bending which takes place within its elastic limit) without breaking. The break will take place largely along the grain boundaries. These grain boundaries consist of thin films of tungsten in the brittle amorphous condition. The amorphous phase has in reality greater cohesion than the crystalline phase at room temperature, but it is under great internal stress due to the difference in coefficient of expansion between it and the crystalline phase.

3. *The Tungsten Wire has a Fibrous Structure.*—To obtain a mental picture of this particular structure, suppose the ingot from which the wire was made was ¼ in. (6·35 mm.) square and contained 3,800 grains per square millimetre. It is worked at temperatures below that of equiaxing so that the grains are progressively elongated from the beginning of working. When the wire is 0·007 in. diameter, the grains will have been changed into fibres the average length of which will be about 1 in. and the average diameter about 0·00002 in. The end of a given metallic fibre will usually not be contiguous to the ends of other fibres with which it is in contact. A tungsten wire with such a structure is ductile cold. It can be drawn cold, bent cold, coiled, &c. It will contain more amorphous tungsten than the fine-grained sample which was brittle. It will be ductile cold because the metal has a tendency to break along the amorphous planes at the grain boundaries and the path of rupture along these will be so great that the break is forced to take place through the crystalline material which, though not as malleable and ductile as the crystalline material before strain hardening, will still possess the properties of malleability and ductility to a certain extent at room temperature. A break through it, therefore, must cause a certain amount of deformation before rupture can take place, thus giving rise to the property of ductility.

4. *The Wire consists of Elongated Grains which have not been Strain-hardened.*—Such a structure results from long heating of tungsten containing thoria or other non-metallic substances. The arrangement of the grains makes a long path for rupture along the grain boundaries, so a much greater load can be applied before rupture than when the metal is composed of equiaxed grains. This makes tungsten possessing an elongated grain stucture stronger or more rugged than the equiaxed structure. At times, such wires even possess slight ductility at room temperature. Electric incandescent lamp filaments frequently possess these elongated grain structures and are as a consequence very rugged.

It is thus seen that the ductility of tungsten at room temperature does not depend on the quantity of amorphous tungsten, but on its arrangement. It has been stated before that the tensile strength of a tungsten ingot is about 18,000 lb. per square inch. Tungsten wire possessing a fibrous structure at 0.007 in. diameter will have a tensile strength of about 340,000 lb. per square inch. The actual cohesion is greater in the drawn tungsten wire than in the equiaxed ingot. The cohesion measured in each case is that of a system made up of what may be considered physically as two separate materials with different properties, but in the case of the equiaxed ingot the internal weakening strains predominate and in the case of the fibrous wire they are eliminated.

As an example of the action of the crystalline and amorphous phases in equiaxed and fibrous tungsten, let us suppose that a structure is made up of grains of iron which we will consider as analogous to the crystalline tungsten, the grains being bound together with very thin films of glass which we will consider analogous to the amorphous tungsten cement surrounding the grains. In the first example, let us suppose that the grains of iron are equiaxed and unstrained—that is, similar to equiaxed tungsten. This structure will assume largely the properties of the brittle glass cement. If a grain of iron could be isolated, it would be malleable, but if the structure taken as a whole is hammered, it will fly to pieces, and if broken in tension, the breaking load will

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be too small to force any marked permanent deformation on the iron grains. This structure will be brittle. If however, the structure were heated to a red heat, at which temperature both iron and glass are known to be workable, then considerable deformation could be effected by hammering or rolling. Let us suppose that such a structure could be rolled or drawn while hot until the dimensions of the deformed iron grains would be comparable to the dimensions of tungsten fibre. The glass film surrounding the grains of iron will remain intact. (In the actual working of the metal, it is very probable that the amorphous films surrounding the grains are made thicker by mechanical working.) Let us further suppose that in this amount of deformation the iron grains will possess some ductility in the cold. When cold ductility tests are made, it will be found that the glass films are no longer in a commanding position, and the path of rupture will be forced largely through the deformed iron grains themselves. Such a temperature with the same quantity of glass present will be ductile at room temperature. It has not been attempted to make the analogy perfect, because glass does not possess the same properties as amorphous tungsten, nor does iron possess the same properties as crystalline tungsten,

Some General Metallographic Propositions.

The discussion in the preceding caption shows why fibrous tungsten is more ductile at room temperature than equiaxed tungsten. Another significant fact has been observed with tungsen, namely, that after the limit of ductility has been reached by working at, say, a red heat, the tungsten after cooling to room temperature or other lower temperatures becomes ductile at these temperatures. Experiments have been made which show that this phenomenon is common to all ductile metals. The reasons have been ascertained. The underlying reason for the loss of ductility by working a metal at a certain temperature below its annealing temperature and the regaining of ductility by cooling to some lower temperature, is that the amorphous phase of any metal will increase in cohesion on cooling, at a faster rate than the crystalline phase. Let us refer to Diagram C. This shows the general cohesion-temperature curves of the amorphous and crystalline phases of metals. The direction of the curves will have to be determined for any given metal, but the general relationship will be found similar to those given in the diagram. The curve traced by a continuous line represents the change in cohesion of the amorphous phase with change in temperature. The cohesion is substantially zero at the melting point of the metal and increases as the temperature decreases, reaching a maximum at absolute zero. The dotted curve represents the change in cohesion of the crystalline phase with change in temperature. The crystalline phase disappears and changes into the amorphous phase when the metal is melted. On cooling from above the melting-point, the crystalline phase forms during solidification and immediately at the melting temperature its cohesion assumes a finite value many times greater than that of the amorphous phase at the same temperature. On cooling below the melting-point however, the crystalline phase increases in cohesion at a very much slower rate than the amorphous phase. At some temperature between the melting-point and absolute zero (in most metals not far from 0.35 to 0.45 of the absolute melting-point) the cohesion of the crystalline phase will be the same as that of the amorphous phase. This temperature I have called the "equi-cohesive temperature." It corresponds in most, if not all, metals, to the lowest equiaxing temperature of the severely cold-worked metal. Just as the equiaxing temperature of the metal is increased with decrease in the time of heating, the apparent equi-cohesive temperature increases as the time of applying the load by which the cohesion is measured is decreased. If a metal is deformed above the equi-cohesive temperature and kept at that temperature, the grains will not remain permanently deformed, but will equiaxe; the properties of the metal will be different after equiaxing. If, however, the grains are deformed below the equi-cohesive temperature, they will remain permanently distorted. Below the equi-cohesive temperature, the amorphous phase has not only greater cohesion than the crystalline phase but its cohesion increases much faster with decrease in temperature.

Let us suppose that Diagram C represents the cohesion-temperature curves of tungsten and that the temperature of wire drawing is 4 *t* deg. The crystalline phase at this temperature has a cohesion of 2 *c* and the amorphous phase 4 *c*. The wire drawing can be continued until the load necessary to break the wire at a temperature of 4 *t* deg. is not sufficient to further deform the crystalline phase. Before any deformation has taken place at 4 *t* deg. the crystalline phase will have a cohesion of 2 *c*, but as the deformation continues amorphous metal will be generated at the planes of slip, and these being in a commanding position will increase the apparent cohesion of the deformed grain. Now let us suppose that room temperature corresponds to 1 *t* deg. The cohesion of the crystalline phase at this temperature is 2.7 *c* and that of the amorphous phase is 8.1 *c*. It will be noted that the amorphous phase at room temperature is 5.2 *c* more cohesive than the crystalline phase, whereas at 4 *t* deg. it is only 2 *c* more cohesive. The limit of ductility at 4 *t* deg. was governed to a certain extent by the difference in cohesion between the amorphous and crystalline phases. By cooling to room temperature this difference has increased 3.2 *c*. If now the metal is subjected to a ductility test at room temperature, a load sufficient further to deform the crystalline phase can be applied before rupture takes place; in other words, the metal is ductile and it has gained ductility because the amorphous phase increases in cohesion with decrease in temperature at a faster rate than the crystalline phase.

One point must not be confused. The limit of ductility of a metal at a certain temperature does not mean that the crystalline phase has been deformed to the greatest possible extent at that temperature. It simply indicates that the load necessary further to deform the crystalline phase cannot be applied to the metal by tension without breaking it. Even though it takes a greater load to deform the crystalline phase at a lower temperature, the increased load which can be applied by tension before rupture takes place (depending largely upon the cohesion of the amorphous phase) will be much more than the increase in the cohesion of the crystalline phase.

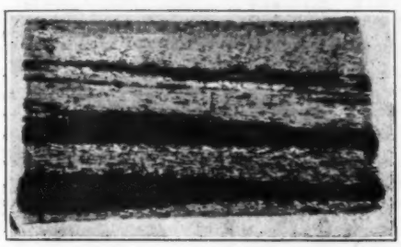

FIG. 54. SPLIT TUNGSTEN WIRE CAUSED BY "OVER-WORKING" OR WORKING TOO COLD. × 170.

FIG. 55. CRACKS AT GRAIN BOUNDARIES IN TUNGSTEN INGOT. × 17.

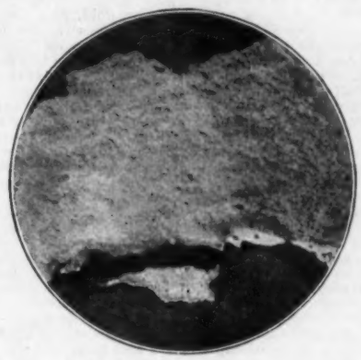

FIG. 56. CRACK PARTLY THROUGH GRAIN IN TUNGSTEN INGOT. × 50

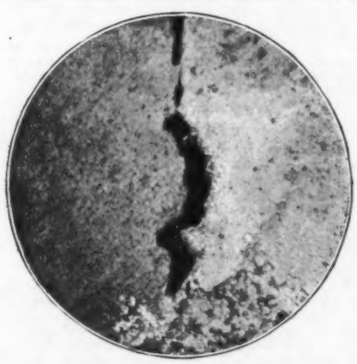

FIG. 57. CRACK BETWEEN TWO GRAINS IN TUNGSTEN INGOT. STOPS AT JUNCTION BETWEEN COARSE AND FINE-GRAINED REGIONS. × 61.

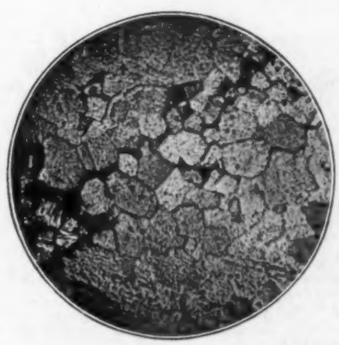

FIG. 58. SHOWS CRACK ALONG GRAIN BOUNDARIES IN FINE-GRAINED TUNGSTEN INGOT. × 144.

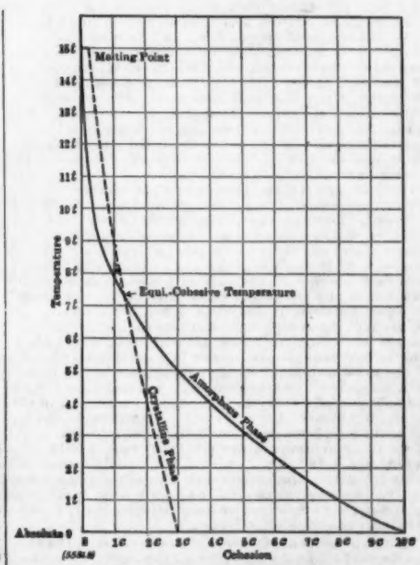

DIAGRAM C. COHESION TEMPERATURE CURVES OF AMORPHOUS AND CRYSTALLINE PHASES OF ANY METAL.

and glass could not be generated within an iron grain during deformation.

That the fracture in tungsten tends to take place along the grain boundaries is shown conclusively in Fig. 55. This fracture was in a coarse-grained sample. One of the cracked boundary lines in Fig. 55 extends to the surface of the tungsten ingot, and the crack does also. In one place where the grain boundary line was rather jagged, the fracture took place through a portion of the crystalline material rather than at the grain boundary. The other cracked grain boundary abuts a fine-grained portion of the tungsten ingot at which the crack stops abruptly. This shows that resistance to rupture is less along a rather straight grain boundary than around the grain boundaries of fine-grained metal. Fig. 56 shows how the crack has jumped across the crystalline portion in preference to following the jagged grain boundary line. Fig. 57 shows the abrupt ending of a crack where the grain boundary line between two large grains intersects a fine-grained area, and Fig. 58 shows that the fracture of a fine-grained area follows in general the grain boundary line. There are two or three cracks in Fig. 42, page 272 *ante*, and it can be plainly seen that these cracks follow the grain boundaries.

That rupture tends to take place along the boundaries of deformed grains in fibrous tungsten can be seen from Fig. 54. That the fracture does not take place entirely along these grain boundaries is due to the fact that the resistance to rupture through the deformed grains or fibres is less in fibrous tungsten than along the deformed grain boundaries. If the deforming load is applied to fibrous tungsten longitudinally, the wire is ductile, but if applied transversely, it is brittle.

Much more deformation can be forced on a given metal at a temperature below that of equiaxing by application of pressure than by tension. Rupturing of metals by pressure, however, must be considered as a natural modification of rupture by tension. A metal, for example, can be subjected to the highest hydrostatic pressures now available without permanently deforming it in the least. Pressures alone, therefore, will not change the external shape of a metal—that is, it will not permanently deform it. Deformation by pressure, therefore, implies a difference in pressure between two parts greater in magnitude than the cohesion of the metal to be deformed. In some cases, during the application of pressure to a metal, certain parts are actually in a state of tension and may break because of it. In other cases all parts of the metal may be subjected to pressure but certain parts will receive enough more pressure than other parts to cause permanent deformation. By utilisation of the property of malleability, a metal may be deformed to a greater extent than by the utilisation of ductility.

It is doubtful whether the actual limit of deformation of any crystalline metal has ever been reached experimentally. The temporary limit ot deformation is always reached when the load necessary to cause it also causes the metal to rupture.

Beilby's observations on copper, gold, and silver fit in with these ideas very nicely. A description of his experiments are here given in his own words:* "Gold, silver and copper ot the highest purity were the metals used. The diameters of the wires at all stages were carefully measured by a micrometer screw gauge. The increases of length by wire drawing were also measured. After a final annealing, wires were drawn to as much as fourteen times their original length. Their tenacity was determined by applying a water load to the vertical hung wire. As stated above, the maximum tenacity was reached in wires drawn from three to five times their original length. A hard-drawn wire shows no general extension even under the breaking load. The broken pieces when brought together show that the small local extension which occurs at the point of rupture may amount to 1 per cent., or less, but it is purely local as proved not only by the absence of any general stretching, but also by a full series of measurements of the diameter at many points along the length. The tenacity was always calculated on the average cross-sections worked out from these measurements. After a large number of experiments had been made at the ordinary temperature, it was decided to repeat these at the temperature of liquid air or—182 deg. The results showed that at this low temperature the tenacity of these metals is very much increased, gold rising from 15.6 tons per square inch at 15 deg. to 22.4 tons at —182 deg., silver from 25.7 tons at 15 deg. to 34.4 tons at — 182 deg., and copper from 28.4 tons at 15 deg. to 36 tons at — 182 deg. The most unexpected result was that all the hard-drawn wires stretched 11 per cent. to 12 per cent. at the lower temperature before breaking. The plasticity which had disappeared at 15 deg. re-appeared at the lower temperature. Our conclusion at the time was that the restarting of plasticity at the low temperature was due to the general increase of tenacity which enabled the wire better to resist the disruptive strains in the die."

Our discussions show that the mere increase in tenacity cannot be responsible for the ductility which Beilby observed. For example, Hadfield[38] found that the ductility of iron decreased with increased tenacity as the temperature was lowered to that of liquid air. What happened in Beilby's experiments was that the tenacity increased faster with decrease in temperature than the cohesion of the crystalline phase due to the differential cohesion between it and the amorphous phase. In Diagram C, let us suppose that room temperature corresponds to 3 t deg. and liquid air temperature to 1 t deg. and the curves as given represent in general the properties of the crystalline and amorphous phases of the metals with which Beilby experimented. At room temperature the cohesion of the crystalline phase is 2.2 c, and of the amorphous phase 5.1 c, while at 1 t deg. the cohesions are 2.7 c and 8.1 c respectively. Beilby had cold-drawn the wires at room temperature till they were brittle. On cooling to — 182 deg. (1 t deg.), the ratio between the cohesion of the amorphous and crystalline phases had greatly increased so that at 1 t deg. tensile load could be applied before the metals ruptured sufficiently further to deform the crystalline phase.

It will be evident, from what has been said, that the metals might be wire drawn at 1 t deg. till they became brittle at that temperature and they would then become ductile if cooled to a temperature of, say, ½ t deg.

A further experiment with wire of aluminium copper alloy also fits in nicely with these fundamental ideas. The wire was worked cold ât room temperature until it would break when bent through an angle of about 60 deg. A piece of wire was then immersed in liquid air and was bent double and straightened again without cracking.

Further confirming evidence is at hand and a rather complete set of experiments dealing with these general problems has now been completed and will be reported in a separate paper. The hypothesis has been sufficiently verified so that results can be predicted from it.

I have considered the application of this hypothesis to substantially pure metals and solid solutions. The application to other classes will be more complicated. Let us take steel as an example. The cohesion-temperature curves of pure iron have jogs in the crystalline curve corresponding to the allotropic points. The approximate curves for iron as well as for cementite would have to be ascertained. In annealed steel, at least three physically different substances will be present; namely, crystalline ferrite, crystalline cementite and the amorphous solution of iron and iron carbide. After cold deformation there may be five physically different constituents present; namely, crystalline ferrite, amorphous iron crystalline cementite, amorphous cementite, and the amorphous solution of iron and cementite. By knowledge of the properties of each of these constituents and their structural position in the steel, predictions may be made regarding the physical properties of the piece of steel taken as a whole.

It should be pointed out that the metals which have the greatest possibilities for improvement by mechanical working, or those metals which should ultimately have high tensile strength whether coupled with ductility or not, should (*a*) possess high unit cohesion in both the crystalline and amorphous phase, and (*b*) the cohesion of the latter should be much greater than that of the former at room temperature. Such metals will have relatively high equi-cohesive temperatures.

In fibrous tungsten, a condition is obtained which makes the ductility greater at room temperature than that of the equiaxed tungsten. The general hypothesis of increase in ductility in metals already possessing fibrous structures by decreasing the temperatures is entirely independent of the relative ductility of the fibrous and equiaxed structures. In Beilby's experiments quoted above, for example the ductility at —182 deg. of the metals with fibrous structures may not have been as great as that of the equiaxed metals at the same temperature. With most, if not all, metals, however, some low temperature will be reached at which the metals in the equiaxed condition will be brittle and the same metals possessing fibrous structures which will have been produced at some higher temperature will be ductile. Iron, for example, possesses these properties at the temperature of liquid air, and tungsten and molybdenum, at ordinary or room temperature.

The amorphous phase of iron is supposed to be brittle at room temperature. It is not sufficiently brittle to cause rupture along the grain boundaries at room temperature. Liquid air temperature, however, will cause coarse-grained iron to fracture along the grain boundaries. A metal with an equiaxed grain structure cannot be very ductile at high temperature because the amorphous phase is weaker than the crystalline. Its ductility (assuming one of the ductile metals) increases on cooling to a certain point, below which it begins to become less ductile. The temperature may be lowered sufficiently to make it brittle.

Experimental proof has also been obtained showing that if a metal is worked at a certain temperature below its annealing temperature, till it becomes brittle at that temperature, it is more brittle at higher temperatures below that of annealing.

ACKNOWLEDGMENTS.

I wish to express my indebtedness to B. L. Benbow, Manager of the Cleveland Wire Division of the General Electric Company, who instigated the work on the metallography of tungsten and under whose direction the work was carried out. I wish also to thank Messrs. L. Cover, L. S. Twomey, E. J. Hull, W. T. Burgoon, and W. F. Sykes, for valuable aid in carrying out the experiments.

BIBLIOGRAPHY.

Preparation of Tungsten Powder.

1. R. A. Hadfield: Alloys of Iron and Tungsten. Journal of the Iron and Steel Institute (No. 2, 1903), vol. lxiv., pages 14 to 38.
2. H. Moissan: *The Electric Furnace*, London, 1904.
3. A. Riche: Recherches sur le Tungstène et ses Composés. "Annales de Chimie et de Physique, Third Series" (1857), vol. l., pages 5 to 80.
4. L. Weiss: Uber das Wolframmetall, *Zeitschrift für Anorganische Chemie* (1909), vol. lxv., pages 279 to 340.
5. Beckert and Brand: Tungsten. *Hüttenkunde* (1895), pages 695 to 697.
6. J. Castner: Wolfram und seine industrielle Bedeutung. *Stahl und Eisen* (1896), vol. xvi., pages 517 to 518.
7. A. Stavenhagen; Zur kenntniss des Wolframs. "Berichte der Deutschen Chemischen Gesellschaft" (1899), vol. xxxii., pages, 1513 to 1516.
8. "Watts' Dictionary of Chemistry," 1902, vol. iv., page 797.
9. H. Mennicke: "Die Metallurgie des Wolframs." Berlin, 1911.

Working of Tungsten.

10. W. D. Collidge: Tungsten and method of making the same for use as filaments of incandescent electric lamps and for other purposes. United States Patent No. 1062933, *U.S. Patent Office Official Gazette* (1913), vol. cxcvii., page 1162.
11. R. W. Moore: Ductile Tungsten. *Metallurgical and Chemical Engineering* (1914), vol. xii., pages 186 to 187.
12. C. G. Fink: Ductile Tungsten and Molybdenum. *Metallurgical and Chemical Engineering* (1910), vol. viii., pages 340 to 341.
13. O. Ruff: Uber die Darstellung streckbaren Wolframs. *Zeitschrift für Angewandte Chemie* (1912), vol. xxv., pages 1889 to 1897.
14. N. L. Miller: Uber das Wolfram und die Geschichte seiner Duktilisierung. *Zeitschrift für Angewandte Chemie* (1913), vol. xxvi., pages, 404 to 407, and 422 to 423.
15. A. Siemans: Metal Filament Lamps. Journal of the Institute of Metals (1913), vol. ix., pages 42 to 60.
16. F. A. Fahrenwald: The Development of Practical Substitutes for Platinum and its Alloys with Special Reference to Tungsten and Molybdenum. Trans., American Institute of Mining Engineers (1916), vol. liv., pages 541 to 593.

On Grain Growth.

17. J. E. Stead: Crystalline Structure of Iron and Steel. Journal of the Iron and Steel Institute (No. 1, 1898), vol. liii, pages 145 to 205. Brittleness Produced in Soft Steel by Annealing. Journal of the Iron and Steel Institute (No. 2, 1898), vol. liv., pages 137 to 184.
18. A. Joiston: Einfluss der thermischen Behandlung auf die Korngrösse des Eisens. *Metallurgie* (1910), vol. vii., pages 456 to 458.
19. A. Sauveur: Note on the Crystalline Growth of Ferrite below its Thermal Critical Range. Proceedings of the International Association for Testing Materials, Sixth Congress, New York, 1912, vol. ii., II$_8$, Discussion Section A, pages 134 to 141. Also "Metallography and Heat Treatment of Iron and Steel." Cambridge, Mass., 1916.
20. M. V. Robin: Recherches sur le Développement des Grains des Métaux par Recuit Après Ecrouissage. "Revue de Métallurgie" (1913), vol. x., pages 722 to 757.
21. W. E. Ruder: Grain Growth in Silicon Steel. Trans. American Institute of Mining Engineers (1913), vol. xlvii., pages 569 to 585.
22. R. H. Sherry: Coarse Crystallisation Produced by Annealing Low-carbon Steel. *Metallurgical and Chemical Engineering*. (1912), vol. x., pages 666 to 667.
23. C. Chappell: The Recrystallisation of Deformed Iron. Journal of the Iron and Steel Institute (No. 1, 1914), vol. lxx., pages 460 to 498.
24. H. M. Howe: Life History of Network and Ferrite Grains in Carbon Steel. Proceedings of the American Society for Testing Materials (1911), vol. xi., pages 262 to 386. On Grain Growth. Trans., American Institute of Mining Engineers (1916), vol. lvi., pages 582 to 599. Recrystallisation after Plastic Deformation. Trans., American Institute of Mining Engineers (1916), vol. lvi., pages 561 to 570.
25. C. H. Matthewson and A. Phillips: Recrystallisation of Cold-worked Alpha Brass on Annealing. Trans., American Institute of Mining Engineers (1916), vol. liv., pages 608 to 658. Discussion, pages 658 to 670.
26. Z. Jeffries; Grain Growth Phenomena in Metals. Trans., American Institute of Mining Engineers (1916), vol. lvi., pages 571 to 581. Discussion, pages 589 to 599.

Amorphous and Theory Plastic Deformation.

27. H. M. Howe: "The Metallography of Steel and Cast Iron," N. Y., 1916. So much of the book applies to the amorphous theory and plastic deformation that specific references need not be given. The same applies to the next reference.
28. W. Rosenhain: "An Introduction to the Study of Physica Metallurgy," N.Y., 1914.
29. G. T. Beilby: The Hard and Soft States in Metals. Journal of the Institute of Metals (No. 2, 1911), vol. vi., pages 5 to 43.
30. G. D. Bengough: A Study of the Properties of Alloys at High Temperatures. Journal of the Institute of Metals (No. 1, 1912), vol. vii., pages 123 to 190.
31. W. Rosenhain and D. Ewen: Intercrystalline Cohesion in Metals. Journal of the Institute of Metals (No. 2, 1912), vol. viii., pages 149 to 185.
32. W. Rosenhain and J. C. W. Humfrey: The Tenacity, Deformation and Fracture of Soft Steel at High Temperatures. Journal of the Iron and Steel Institute (No. 1, 1913), vol. lxxxvii., pages 219 to 314.
33. J. C. W. Humfrey: Influence of Intercrystalline Cohesion on the Mechanical Properties of Metals. Iron and Steel Institute, Carnegie Scholarship Memoirs (1913), vol. v., pages 86 to 99. Intercrystalline Fracture of Iron and Steel, Idem (1912), vol. iv., pages 80 to 107.
34. Zay Jeffries: The Amorphous Metal Hypothesis and Equi-cohesive Temperatures. Bulletin, American Institute of Metals (December, 1917), pages 300 to 324.

Miscellaneous.

35. A. Siemens: Tantalum and its Industrial Application. Proceedings, Royal Institution of Great Britain (1909), vol. xix., pages 590 to 597.
36. M. G. Timofeeff: Sur la Récristallisation du Zinc Écroui. "Revue de Métallurgie" (1914), vol. xi., pages 127 to 132.
37. C. L. Bloxam: "Metals, their Properties and Treatment," New Edition, 278. London, 1888.
38. R. A. Hadfield: Experiments relating to the effect on mechanical and other properties of iron and its alloys produced by liquid air temperatures. Journal of the Iron and Steel Institute (No. 1, 1905), vol. lxvii., pages 202 to 255.

* *Journal of the Institute of Metals* (No. 2, 1911), 6, 19.

CATALOGUES.

Electric Switches.—Thirteen classes of lever switches each made in a full range of sizes, are set out in full particular in a special catalogue issued by the British Thomson-Houston Company, Limited, Rugby. These are suitable for main circuit, field breaking, motor starting and isolating and for alternating or direct currents.

Flour Mill.—Some circulars from Mr. A. R. Tattersall 75, Mark-lane, E.C. 3, deal with the "Midget" flour mill of which he is the patentee and maker. It is a "short system" mill, the object of the invention being to provide a comparatively small plant, capable of economical production on a small scale so that the wheat grown in a limited area could be milled for consumption within that area. The mill is a complete roller plant contained in one frame, driven by one belt and suitable for erection in a one or two storey building. Apparently the best way would be a special building for the machine with a driving belt passing in from a power unit outside. We infer that there are several sizes as the capacity is given as 200 lb. to 600 lb. of wheat per hour. These machines generally work 24 hours per day at certain seasons and may then be laid up for a period. The claims as to quality of work include the following: French army official test states that 80 per cent. of the flour went through No. 60 and No. 80 French silk sieves. A yield of 43 lb. of flour from 58 lb. of wheat; the quality is graded in the laboratories at Chicago and this product is certified "99 per cent. grade," which, we assume, is within 1 per cent. of perfect quality. It is of some interest to note that Mr. Tattersall was awarded a medal for his invention by the City of Philadelphia on the recommendation of the Franklin Institute. The medal and premium is granted under the will of Mr. John Scott, of Edinburgh, Scotland. (See page 258 *ante*.)

THE SCHOOP METAL-SPRAYING PROCESS.—From Zürich comes the news of another improvement of the Schoop process. Instead of melting the metal, which is generally applied in the shape of a wire, by the oxy-hydrogen flame or the blowpipe, electric fusion is now used and is said to be both simpler and cheaper. The pistol apparatus is employed as before; but two ends of the wire are placed in the pistol, instead of one, and they are approached to one another as electrodes of an electric circuit. When the arc strikes, the wire fuses, and the air current tears the fine metallic particles away. Zinc sprays in particular have been produced in this way, according to Kasperowicz (*Zeitschrift für Angewandte Chemie*, July 23, 1918). The electric heating may be simple, but the prevention of the oxidation of the sprayed metal will probably be as difficult as before.